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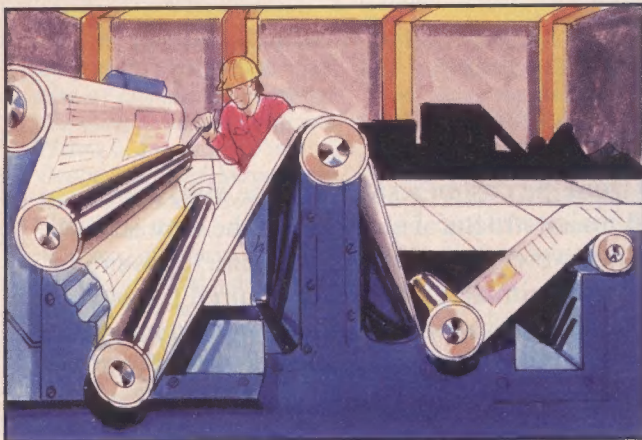
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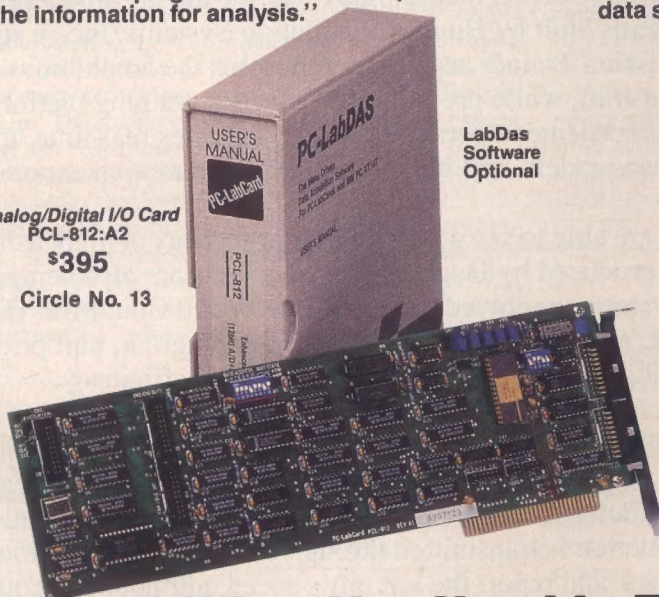


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Inexpensive aluminum clips help trim nearly \$200,000 from the cost of a satellite. The clips were designed and used by Hughes Aircraft Company to hold major structural elements of the new HS 601 communications satellites together. Previously the satellites were bonded together, a time-consuming process because of the close tolerances involved and the approximately one week required for each bond to cure. With about 250 structural joints per satellite, the clips save nearly \$200,000 in hands-on labor per spacecraft. Another benefit of the technique is the elimination of bond testing. Verifying the torque, a much faster process, is all that's required with the new process.

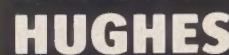
The U.S. Navy now has the first full-function simulator for military hovercraft. This amphibious vehicle, called the Landing Craft Air Cushion (LCAC), incorporates state-of-the-art hovercraft technology. It is one of many training systems built by Hughes Simulation Systems, Inc., a subsidiary of Hughes Aircraft Company. The Full Mission Trainer accurately replicates the amphibious environment and dynamic responses of the craft, while providing an effective training platform for all crew positions. LCAC simulates many unprecedented operations at sea. It creates real-time, multiple sea-state, three-dimensional wave and ocean models, and integrates visual and motion experience.

Gunners in U.S. Army M1 Abrams tanks are able to see and pinpoint targets day or night using laser rangefinder and thermal imaging systems produced by Hughes. These systems are also being applied to advanced fire control and air defense systems employed by other Free World Countries. Deliveries of the systems have passed the 8,000 mark, and over the 10-year life of the program, unit prices have decreased nearly 50 percent as the result of significant increases in production efficiency.

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NEWSLOG

DEC 10: The Mexican Government said it would sell 20.4 percent of its national telephone company, **Teléfonos de México (Telmex)**, to a consortium of **Grupo Carso** of Mexico, the **Southwestern Bell Corp.**, based in St. Louis, Mo., and **France Télécom**, in Paris. The US \$1.76 billion deal is among the biggest in a series of recent sales of telephone companies by governments around the world.

DEC 12: Hitachi Ltd., Tokyo, said it developed what it described as the world's smallest static RAM cell, an advance that could allow development of a new generation of SRAM chips. The company said it made the 5.9-square-micrometer experimental cell with new technology that let it achieve greater resolution during etching. If incorporated into a SRAM of 16M bits, the new cell would require less than 1/10 of a microwatt of power to hold data.

DEC 12: Texas Instruments Inc., Dallas, in its largest round of patent battles with Japanese chip companies, signed a 10-year, multimillion-dollar licensing agreement with **Toshiba Corp.**, Tokyo. The agreement marks the first time a Japanese chip company has agreed to pay royalties to the Dallas chip maker since TI won a key patent in Japan in 1989, nearly 30 years after applying for it.

DEC 13: Motorola Inc., Schaumburg, Ill., said it would produce its next generation of 4M-bit dynamic RAM chips in a Japanese factory as part of a joint venture with **Toshiba Corp.**, Tokyo. The plant, to be jointly run by both companies, will be located at Tohoku Semiconductor Corp. in Sendai.

DEC 14: The Environmental Protection Agency (EPA), Washington, D.C., issued a report concluding that enough

evidence exists of a possible link between cancer and low-level (60-megahertz) electromagnetic fields from power lines and household appliances to warrant new research. The study must be reviewed by higher-level EPA boards before the conclusions become policy.

DEC 13: The Nuclear Regulatory Commission, Rockville, Md., tightened radiation-exposure limits, the first revision of its standards in over 30 years. To take effect in 1993, the regulations require exposing the general public near atomic installations to no more than a fifth of the annual radiation now allowed and atomic workers to one-fourth the present maximum.

DEC 16: The oldest working spacecraft, Pioneer 6, which is exploring solar activity, celebrated its 25th anniversary in space. Launched in 1965 from Cape Canaveral, Fla., and designed with a minimum life expectancy of six months, it has never stopped functioning, having circled the sun more than two dozen times and traveled 15.4 billion miles (24.8 billion kilometers).

DEC 17: AT&T Co. and Zenith Electronics Corp., Glenview, Ill., said they would jointly develop an all-digital high-definition television system (HDTV). The joint venture will be one of six competing systems evaluated by the **Federal Communications Commission**, Washington, D.C., in tests beginning in April to adopt a U.S. HDTV standard.

DEC 19: Digital Equipment Corp., Maynard, Mass., in its largest overseas venture to date, said it agreed to invest DM 350 million (US \$230 million) for 65 percent of a new company it will form with the **Kienzle Computer Systems Division** of German conglomerate **Man-nesmann AG** in Düsseldorf.

The resulting company, **Digital-Kienzle Computer Systeme**, will be based in Villingen, Germany.

DEC 27: San Francisco became the only U.S. city to regulate the use of videodisplay terminals in the workplace to reduce the risk of ailments caused by prolonged use. A new law, which applies to companies with 15 or more employees, requires that workers be provided with adjustable chairs, proper lighting, and terminals with adjustable screens and detached keyboards, and that they be given 15-minute breaks or alternative work after every 2 hours at the terminal. Businesses will have four years to fully comply with the ordinance; violators could be fined as much as \$500 a day.

DEC 31: Experts on the Soviet Space Program said an abandoned 40-ton Soviet space station will plunge to earth in fiery debris, most likely sometime in February. The 90-foot (27-meter) craft, **Salyut 7**, which was lofted in 1982, is traveling as far north as 51.6 degrees latitude, over Canada, and as far south as 51.6 degrees, the southern tip of South America.

JAN 2: Dataquest Inc., a market research company in San Jose, Calif., reported that U.S. semiconductor companies gained market share in 1990 from their Japanese competitors for the first time in more than a decade, raising their proportion of worldwide sales to 36.5 percent from 34.9 percent in 1989, while that of Japanese companies fell to 49.5 percent, from 52.1 percent.

JAN 3: The Food and Drug Administration, Washington, D.C., gave the **Texas Heart Institute at St. Luke's Episcopal Hospital** in Houston approval to begin experimental use of a portable, battery-powered

mechanical device to help a failing heart pump blood until a heart donor can be found. The device manufacturer, **Thermo Cardiosystems Inc.**, Woburn, Mass., said it is the first heart device without external connections.

JAN 7: The United States will buy an advanced type of nuclear reactor built by the Soviet Union for \$10 million, the first major sale of sensitive space technology with military potential between the two countries, **Senator Pete V. Domenici** (R-N.M.) announced at a scientific symposium on space nuclear power in Albuquerque. The reactor is an advanced version of devices that have powered Soviet spy satellites for decades.

JAN 7: U.S. Defense Secretary Dick Cheney canceled plans to build a new Navy attack plane, the **A-12**, the largest weapons program ever terminated. The Pentagon said the builders of the \$57 billion radar-evading stealth warplane program—**McDonnell Douglas Corp.** and **General Dynamics Corp.**, both based in St. Louis—had defaulted on the program by allowing delays and cost overruns. Both companies denied the charges and said they would challenge the ruling.

JAN 8: Tokyo's NEC Corp. and Mitsui & Co. said they had won an order for an Intelsat earth station from the central Soviet republic of Uzbekistan. It is the first time a Soviet republic has ordered such a station, which will be installed by year-end in Tashkent.

Preview:

FEB 17-23: National Engineers Week 1991 is celebrated, with 15 engineering organizations sponsoring activities highlighting the week's Discover "E" program theme: "Engineering our Environment."

Coordinator: Sally Cahur

IEEE SPECTRUM

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Cover: In the mid-1990s, color workstations like this prototype from IBM Corp., called the common console, will begin to replace the round monochrome screens and paper strips of flight information now used by U.S. air traffic controllers. Flexibility in reconfiguring the display of air space as well as advanced software tools are expected to make the U.S. air transportation system safer and more efficient. See p. 22.

Photo: IBM Corp.

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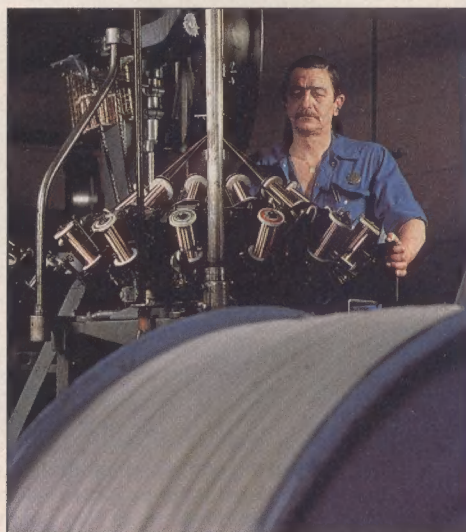
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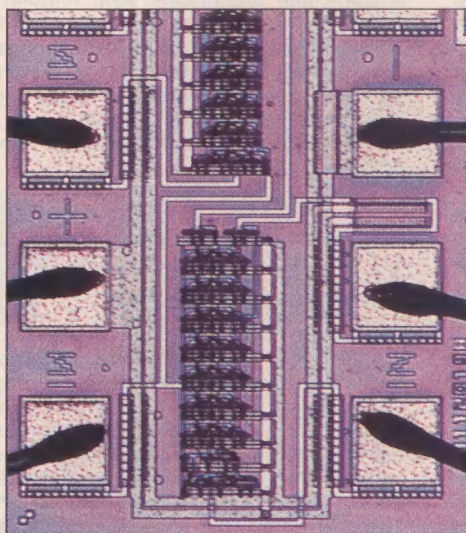
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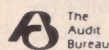
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Technical care for a world in distress

I observe a fantastic array of talent in the IEEE struggling to find something useful to do now that things have cooled down with the USSR. I hope that our preoccupation with weapons development will not blind us to the urgent need of the United States and the world for solutions to environmental problems. These problems are so big they may, in a very few years, wipe many of us out, even without nuclear weapons or war.

It is impossible to exaggerate the rate of devastation taking place now, under our very noses, in massive overcuts of our forests, in overfishing and poisoning of the oceans from agricultural and city drainage as well as oil spills, in forest decline due to acid rain, in global temperature rise and an ozone hole, in an auto industry that, together with government, fails to move in the direction of reduced fuel use and lowered pollution, and a waste disposal industry that is polluting almost without control by government. I admit that many of these problems would be called political, but many also need technical help from scientists and technologists who give a damn.

*John Sinclair
Little River, Calif.*

Many miss out on math, science

I greatly appreciated Walter W. Frey's comments in "Schools miss out on dyslexic engineers" [December, p. 6]. Particularly striking was his insight into the educational system's undermining of those for whom math and science are problematic.

I am an undeniably right-brained—and, I strongly suspect, compensated mild dyslexic—writer, actress, and director. I am also a product of one of the pilot programs of the 1960s whose initial impulse was to inspire children in disadvantaged neighborhoods who showed signs of high aptitude to learn. Though I feel the program was right on the money in many ways (it succeeded masterfully in elevating children's reading levels), it did not appear either to promote interest in math and science or to encourage innovative approaches to them. Hence, I and many of my schoolmates were, as Frey suggests, steered away from them.

The implications of this are indeed far-reaching when one stops to consider the fact that we were predominantly black and Hispanic children in the south Bronx in New York City. My curiosity and concern are piqued, then, by the statistics on dyslexia in poor communities as it directly relates to the projected dearth of scientists and engineers over the next 10 years (which I have read about in previous issues of *Spectrum* and elsewhere), coupled with the increasing strain on job availability also explored in the December issue [pp. 32-43].

The tactic of using unfair testing practices to systematically weed out "un-

desirables" from prestigious schools and, ultimately, professional or specialized lines of work is a tragic and insidious tradition in the United States. Equally tragic has been the degree to which "silent challenges" such as dyslexia, deafness, and learning disabilities have gone unnoticed altogether.

I wholeheartedly agree with Frey's implication that the etiology of an individual's difficulty with learning and/or retaining mathematical and scientific data is often automatically presumed to be merely her/his limited aptitude for grasping these disciplines. But the tricky part is in confronting the reasons for this when it occurs in schools where poor black and Hispanic children are in the majority.

Whereas the open acknowledgment of left-brain/right-brain difference as a universal reality is relatively new, the tacit yet shockingly resounding belief that black and Hispanic people are inherently inferior in aptitude still thrives in many educational systems in this country. This bias can serve to obscure what may be a repairable problem by erroneously equating specific racial origins with genetic predisposition to a lack of aptitude. This, in turn, permits learning disabilities and deafness to be overlooked and/or misdiagnosed when they are present in children who live and attend school in predominantly black or Hispanic communities. As a result, significant groups of potential engineers and scientists are, as Frey points out, steered away from even entertaining the idea that they may have something to contribute to these specialized fields—or to anything else, for that matter.

Because I was one of those children "programmed" away from the mathematical and scientific realm, I spent many years unaware of the ways in which science and technology even remotely related to me, let alone that I might have something to contribute to them. Hence, I was especially heartened by Frey's comments, and by the realization that I had been moved to respond to them.

Here's hoping it's never too late to be reprogrammed.

*Jaye Austin-Williams
Brooklyn, N.Y.*

Developing an amplifier

The feature "Keithley's phantom repeater" [December, p. 71] was of especial interest to me because of my experience during World War II. Early in the war, the NOL began ordering instruments from my then company, Offner Electronics. I was asked to develop a highly sensitive magnetometer and supply a stable, high-gain, dc amplifier to amplify the voltage produced in the transducer by any variations of the ambient magnetic field.

I was faced with a difficult problem: how to connect the amplifier to the transducer, necessarily through a long shielded cable, without the signal being lost, or at least being severely distorted by the capacitance of the cable. The answer suddenly

hit me: keep the shield always at the same potential as the signal being transmitted—in other words, a "driven shield." On its first trial, this worked perfectly. I brought the equipment to the NOL and demonstrated it to the staff.

One thing troubled me for some time about my driven shield concept: it seemed that I was getting something for nothing. This was cleared up when I realized that the loss in signal-to-noise ratio due to the capacitance across the input was not reduced—only its effect on the frequency response was eliminated.

The driven shield principle, otherwise known as "boot-strapping," was used by others to eliminate capacitive effects in the amplifier itself. The amplifier made by Professor Jerome Letvin at the Massachusetts Institute of Technology in Cambridge was a highly successful example of such an amplifier.

*Franklin F. Offner
Evanston, Ill.*

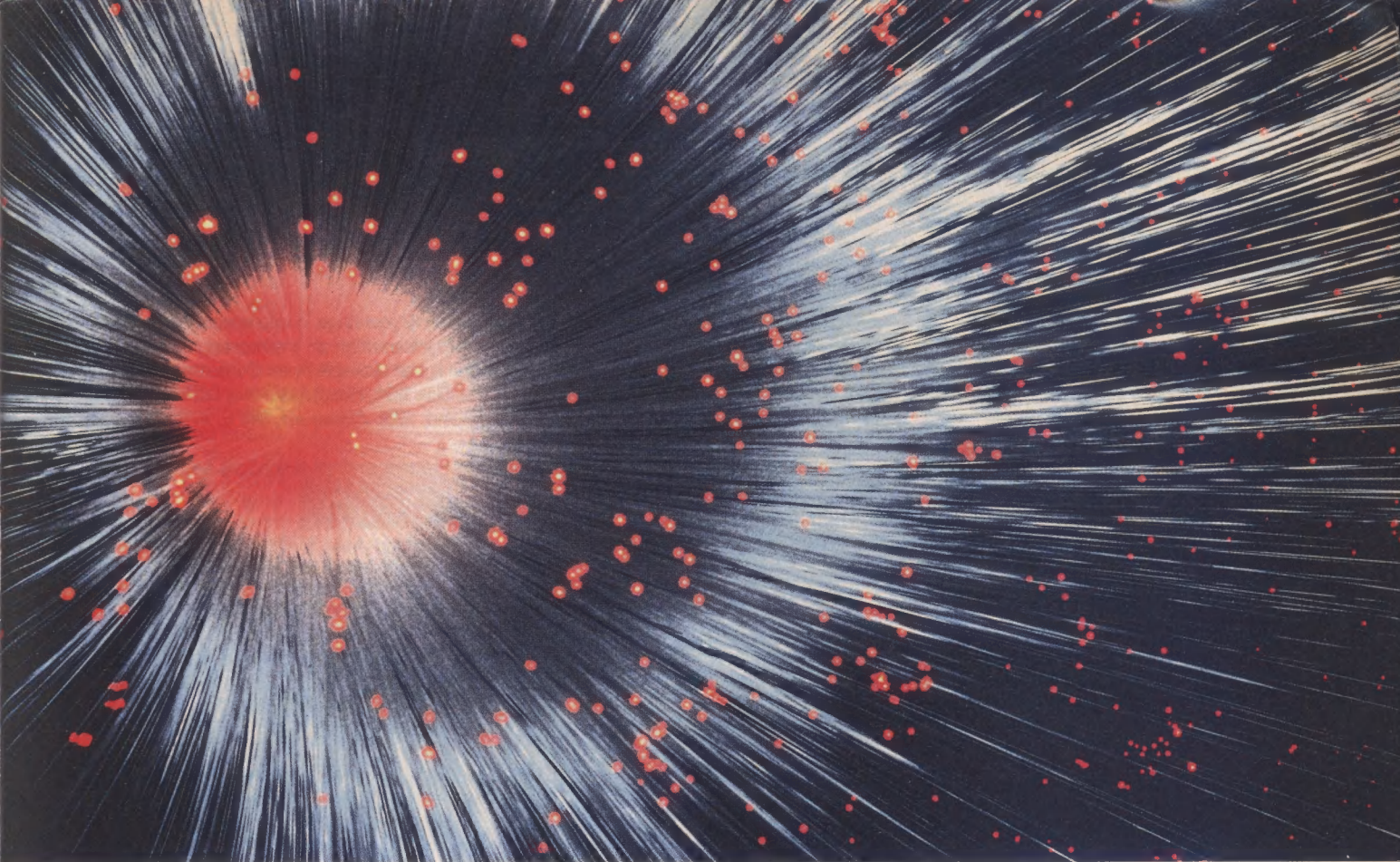
EMF not a health risk?

It was interesting to note that the special report "Electromagnetic fields: the jury's still out" [August, p. 22] did not mention one case where the jury came back. In 1985, Klein Independent School District was sued by Houston Lighting & Power Co. because the district would not allow the company right-of-way to run a power cable across school property. After some deliberation, the jury, surely the nearest thing we have to an impartial observer, ordered removal of the power line (which the power company had installed), the payment of actual damages, and punitive damages. The appeals court later squashed the punitive damages award but upheld all other awards against the power company. The appeals court went on to say that there was "clear and convincing evidence" of hazards to health from the radiation associated with the power line.

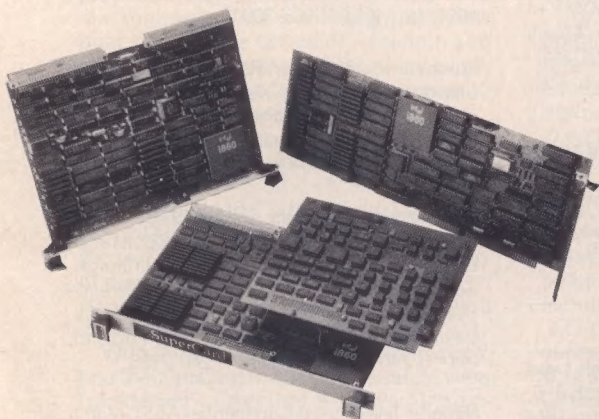
The article also failed to note that the initial Rhode Island study was discredited. When its data were taken and analyzed correctly, it no longer gave a negative correlation between childhood cancer and power-line radiation. (The original researchers were invited to comment on the reworked analysis but declined.) The original study also added a confusion factor as its authors compared it to an earlier study to which it was not directly comparable because of significant differences in wiring configurations.

The special report states that David Carter has suggested that as many as 30 percent of the childhood cancers in the United States are attributable to 60-hertz radiation. It goes on to note that this is only 1 chance in 33 333 per year of any one child contracting the disease; an alternative approach to Carter's statement is that as many as 2000 children are dying unnecessarily and painful deaths each year in this country. It is all a matter of how the data are viewed, but an individual's choice does

(continued on p. 58)



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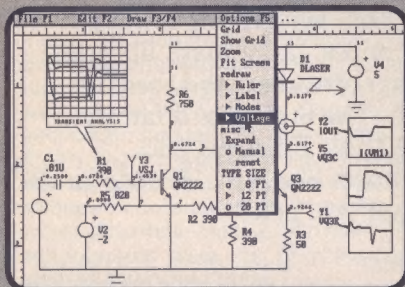
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IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855; 908-562-3878; submit conferences for listing to: Rita Holland, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017; 212-705-7569.

For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

FEBRUARY

International Solid State Circuits Conference (ISSCC et al.); Feb. 13-15; San Francisco Hilton, San Francisco; Diane Suiters, Courtesy Associates, 655 15th St., N.W., Suite 300, Washington, D.C. 20005; 202-639-4255.

Optical Fiber Communication Conference (COM, LEO, et al.); Feb. 17-22; Convention Center, San Diego, Calif.; OFC Conference Management, Optical Society of America, 2010 Massachusetts Ave., N.W., Washington, D.C. 20036; 202-223-0920 or 202-416-1950.

11th Nonvolatile Semiconductor Memory Workshop (ED); Feb. 19-22; Hyatt Regency Hotel, Monterey, Calif.; Theodore Dellin, Sandia National Laboratories, Division 2146, Box 5800, Albuquerque, N.M. 87185; 505-844-2044.

Conference on Communication in Distributed Systems (German Section, ITG); Feb. 20-22; University of Mannheim, Germany; Secretariat, German Section IEEE, Stresemannallee 15, D-6000 Frankfurt 70, Germany; (49+69) 630 8221.

Seventh International Conference on Artificial Intelligence Applications-CAIA 91 (COMP et al.); Feb. 24-28; Fontainebleau Hilton, Miami Beach, Fla.; IEEE Computer Society, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013.

Computer Society Conference-COMPCON Spring '91 (COMP); Feb. 25-March 1; Cathedral Hill Hotel, San Francisco; COMPCON Spring '91, IEEE Computer Society, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013.

MARCH

Fifth International Workshop on High-Level Synthesis-HLSW (COMP et al.); March 3-6; Buelerhoge, Germany; Raul Campusano, IBM Thomas J. Watson Research Center, Box 218, Yorktown Heights, N.Y. 10598; 914-945-3871.

Electronics and Instrumentation Conference and Exhibit (ISA/IEEE); March 6-7; Cincinnati Convention Center, Cincinnati, Ohio; Orest M. Melnyk, IEEE, Box 15044, Cincinnati, Ohio 45215; 513-397-1044.

Applied Power Electronics Conference and

Exposition-Apec '91 (PEL); March 11-15; Hyatt Regency Dallas, Dallas; Ann Beightol, Courtesy Associates, 655 15th St., N.W., Suite 300, Washington, D.C. 20005; 202-347-5900.

IEEE National Radar Conference (LA Council, AES); March 12-13; Sheraton Plaza La Reina Hotel, Los Angeles; David Lynch, Hughes Aircraft Co., 213-334-5442.

Topical Meeting on Picosecond Electronics and Optoelectronics (ED); March 13-15; Marriott Hotel, Salt Lake City, Utah; Jarus W. Quinn, Executive Director, Optical Society of America, 1816 Jefferson Place, N.W., Washington, D.C. 20036; 202-223-8130.

Fourth Annual Computer Virus & Security Conference (IEEE-CS); March 14-15; World Trade Center, New York City; Lorna, IEEE Computer Society, Conference Services, N.J.; (201) 981-0060.

International Conference on Microelectronic Test Structures (ED); March 18-20; Kyoto Grand Hotel, Kyoto, Japan; Takashi Ohzone, Semiconductor Research Center, Matsushita Electric Industrial Co., 3-15 Yagumo-Nakamachi, Moriguchi-shi, Osaka 570, Japan; (81+6) 906 4891; fax, (81+6) 906 3994.

European Workshop on Refractory Metals and Silicides (ED); March 24-27; Var Gard, Saltsjobaden, Sweden; S. Petersson, Swedish Institute of Microelectronics, Box 1084, S-16421, Kista, Sweden; (46+8) 752 1401.

International Conference Control '91 (UKRI Section); March 25-28; Edinburgh Conference Centre, Heriot-Watt University, Edinburgh, Scotland; Louise Bousfield, IEE Conference Services, Institution of Electrical Engineers, Savoy Place, London WC2R 0BL, England; (44+1) 240 1871; fax, (44+1) 240 7735.

National Telesystems Conference (AES); March 26-27; World Congress Center, Atlanta, Ga.; Scott Wood, Scientific-Atlanta, 3845 Pleasantdale Rd., Atlanta, Ga. 30340; 404-925-6377.

Southcon/91 Electronics Conference and Exhibition (Region 3, Atlanta Section, Florida C); March 26-28; Georgia World Congress Center, Atlanta; Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, Calif. 90045-3194; 800-877-2668; fax, 213-641-5117.

Science and the Navy: The History of the Office of Naval Research. Sapolsky, Harvey M., Princeton University Press, Princeton, N.J., 1990, 142 pp., \$24.95.

In the decade that followed World War II, the Office of Naval Research (ONR) was the only significant source of Federal support for basic academic research in the United States. The work that the office supported had a profound impact on the post-war evolution of U.S. science and technology.

The first few chapters of this superb book chronicle the series of bureaucratic accidents that brought ONR to its central position and explain how, over time, other institutions gradually supplanted it. Later chapters provide insightful analysis of a number of issues in Federal science policy and civilian science advice to the military.

Shortly before the war, Vice Admiral Harold G. Bowen recognized in atomic energy great promise not just for weaponry, but also for ship propulsion. Sapolsky reports that, as chief of the service's Bureau of Engineering, Bowen set out to build an institutional base in the Navy through which he could direct the development of atomic ship propulsion. However, his brash style won him so many enemies, both inside and outside the service, that he lost his Bureau of Engineering assignment.

Instead, during the war, he was appointed technical assistant to the Secretary of the Navy, and built a close relationship with James Forrestal, then undersecretary of the Navy. So when Forrestal was promoted to Secretary in 1944, Bowen's star rose again. He received a major new post, head of the Office of Research and Inventions (ORI), from which he once again began to maneuver to build a program to develop atomic propulsion.

The Navy's relations with civilian scientists were coordinated during the war by a group of young officers, known as the "bird dogs," in the Office of the Coordinator of Research and Development. Near the end of the war, they developed a series of proposals for Navy support of basic civilian research, which they tried but failed to sell to the Secretary of the Navy.

With the creation of ORI, the bird dogs, and their interest in civilian research, were transferred to Admiral Bowen's jurisdiction. While he had previously opposed civilian involvement in Navy research, he now worked hard to obtain new legislative authority for an Office of Naval Research and, once he obtained it, to vigorously promote the bird dogs' ideas as vehicles to build an atomic propulsion R&D program. Unfortunately for him, at a crucial moment in the struggle, Forrestal became preoccupied with other matters, and in a classic bureaucratic battle, Bowen lost atom-

ic propulsion to the Bureau of Ships, where Captain Hyman G. Rickover took over the new program.

Having failed in his objective, Bowen went on terminal leave, leaving in place a strong ONR with a vigorous staff freed to pursue their dream of supporting basic civilian research. The office embarked on its new venture by sending delegations to key research universities, to persuade them that they should accept Navy money for basic research—and that such support would not jeopardize academic independence.

These delegations succeeded with university administrators by agreeing to provide full-cost recovery, including overhead, and with scientists by agreeing to administer the contracts as if they were grants. Basic physical science research was supported through the "science branch," which presided over programs in physics, nuclear physics, mechanics and materials, electronics and communications, mathematics, and fluid mechanics. There was also a "medical science branch," which supported research in physiology, biochemistry, bacteriology, psychology, psychophysiology, biophysics, and enviro-physiology. A "program branch" supported work more directly relevant to the Navy's needs, but even here the research done in areas such as geophysics was in some cases rather fundamental in nature.

A number of regional offices were opened around the country. The wartime London liaison group of the Office of Scientific Research and Development was converted into ONR-London, which continues to this day to produce excellent monthly reports on the status of European science and engineering (readers interested in this service can write for more information to the Office of Naval Research European Office, Box 39, FPO New York, N. Y. 09510-0700).

As the war ended, Vannevar Bush, the politically astute coordinator of the wartime civilian research effort, proposed the establishment of a National Science Foundation (NSF) in his famous report *Science: The Endless Frontier*. While ultimately successful, this proposal spent several years bogged down in political wrangling between Congress and the President. Then, once established, NSF was slow in getting going. In the intervening years, ONR prospered, and with it, U.S. basic research in science and technology.

Eventually, in the face of budgetary pressures, the Navy began to question why it was supporting so much basic research. Critical examination slackened off during the flood of funding from the Korean War, but ONR was steadily required to tie the work it supported more and more closely to specific Navy missions. By the 1960s, other institutions, most notably the NSF and the National Institutes for Health, had largely replaced the ONR as the central supporters of basic research. Sapolsky chronicles these shifts, as well as the tensions that developed during the Vietnam era, when many scientists learned—to

their embarrassment—that their benignly titled ONR basic research grants had been given horrendous-sounding internal Navy titles, to buttress internal justification.

Despite its gradual eclipse, ONR has gone on making important contributions to basic research. A notable if unlikely example, which, unfortunately, Sapolsky does not discuss, is a recent effort in behavioral decision theory and human decision making under uncertainty.

The fifth and sixth chapters explore a number of broader issues in science policy, focusing on the problems of providing independent science advice to the military. These problems have often been acute in the case of the Navy, which has a tradition of stubborn independence. Sapolsky's thoughtful analysis will be of interest to most readers with concerns in science policy. Casual readers will probably find the final chapters less absorbing than the straightforward historical reporting of the book's earlier chapters.

Sapolsky's little volume is a first-rate addition to the literature on U.S. science policy. It deserves a place alongside such classics as Thomas Manning's *Government in Science: The US Geological Survey 1867-1964*, Daniel Kevles' *The Physicists: The History of the Scientific Community in Modern America*, and Daniel Greenberg's irreverent *The Politics of Pure Science*.

—M. Granger Morgan

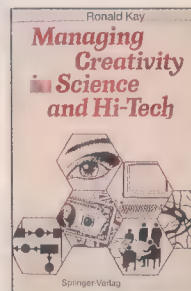
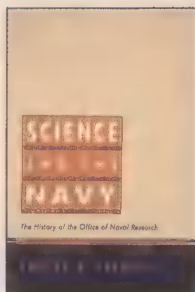
M. Granger Morgan is head of the department of engineering and public policy at Carnegie Mellon University in Pittsburgh, where he is also a professor in the department of electrical and computer engineering. His research deals principally with problems of technology and policy. He is a member of THE INSTITUTE's editorial board.

Managing Creativity in Science and Hi-Tech. Kay, Ronald, Springer-Verlag, Berlin, 1990, 221 pp., \$29.95.

What is it that impels nearly everyone who has ever managed R&D to write the definitive book on how to manage technology, innovation, or creative people? In my judgment, the last word on the subject has already been said, almost 20 years ago, in the brief

but classic work by Jack Morton, *Organizing for Innovation* (McGraw-Hill, New York, 1971). Now, along comes another book purporting to let would-be managers of technical enterprise in on the secrets of stimulating creative people and maximizing their output in a technical environment.

Comparison of Ronald Kay's book with Morton's inspires me to paraphrase Senator Lloyd Bentsen's remark during the 1988 presidential campaign: Kay is no Morton. Whereas Morton recounted the Bell Laboratories experience in detail and traced the role of management in the emergence of the Lab's numerous seminal



innovations, Kay derives generalizations from anonymous allegedly fictional examples—but which surely represent the author's experiences at IBM, where, according to the dust jacket, he spent most of his career. (His comments on startups, though, are a most helpful part of his book.)

Morton teased out cause-and-effect relationships between the subtleties of management as practiced at Bell Labs and their research output in science, engineering, and a host of celebrated and storied innovations. Kay, on the other hand, deals in abstractions rooted neither in explicit examples of output nor in the personalities of the people involved.

Principles of good management cannot be taught in the abstract; they must be related to life, much as a mathematician solves a problem by building on one that has already been solved. In the absence of specifics, it is difficult to dispute Kay's conclusions except by identifying examples that belie them. One is the assertion (p. 153) that successful startups must be market- rather than technology-driven. If that were so, the copier and personal computer would have had a long wait before seeing the light of day. There are many such counter-specifics to the author's sweeping statements.

The chapters on managing creative people that constitute the first half of Kay's

book would have been of more value to the aspiring manager of technical activities if they had been patterned, as in Morton's book, on a historical perspective of R&D contributions to innovation. Such a perspective might parallel published descriptions of the characteristics of the innovative process unique (or not so unique) to other celebrated research institutions, such as DuPont Co. (Gee), Xerox Corp. (Smith and Alexander), and General Electric Co.

Nonetheless, the second part of the book, which concerns startups and venture capital, is an excellent primer on a subject that should be of keen interest to many technical managers. Indeed, the explosive need for creative management in the small high-tech startup and its relationship to creative management in the large enterprise is of great pertinence to the present and is treated admirably by the author. Had this book been a pamphlet containing the four chapters on this limited universe, the author would be receiving nothing but kudos in this review.

—Jack E. Goldman

Jack E. Goldman is chairman and chief executive officer of Cauzin Systems Inc., a Waterbury, Conn., company that produces Softstrip, a paper-based data storage system for personal computers. In 1983, he retired as senior vice president for research and development and chief scientist of Xerox Corp. Before that, he was research director for Ford Motor Co. He has served on various government and industrial advisory boards and is a regular contributor to this column.

On the Shoulders of Giants: New Approaches to Numeracy. Edited by Lynn Arthur Steen, National Academy Press, Washington, D.C., 1990, 232 pp., \$17.95.

"Like cholesterol in the blood, mathematics can clog the educational arteries of the nation," writes editor Lynn Arthur Steen. Bad math lessons can also discourage pursuit of careers in science and engineering. This collection of essays by five experts seeks to cleanse the arteries (before the patient develops a heart attack).

Because computers and calculators excel in precisely the computational problems that schools have emphasized for centuries, coursework should shift emphasis, the authors contend. Learning about patterns and order of all sorts should supplement traditional school exercises with numbers and shapes, Steen argues. Computers and associated graphics become enabling tools and "thinking aids."

The essays (on dimension, quantity, uncertainty, shape, and change) are generously illustrated and written by leading authorities on mathematics and statistics. Most of these authorities, some of whom represent major universities, have written for the popular press and do not hesitate to criticize.

"In our schools identification and classification of shapes usually stop just at the point where they can begin to be really

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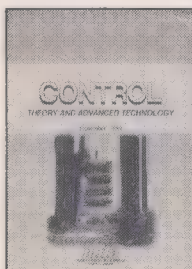
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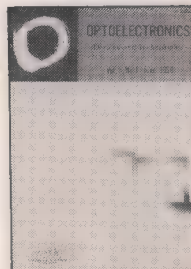
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interesting—where they begin to explore structures in three-dimensional space,” writes Marjorie Senechal of Smith College, Northampton, Mass. For instance, many molecules have crumpled polygonal shapes that often are key to their chemical properties.

Those who think of math teaching (and learning) as stale rote will be surprised by this collection—if they ever read it. Perhaps it would make a good homework assignment for some teachers.

—John A. Adam

Coordinator: Glenn Zorpette

RECENT BOOKS

Power Electronics Handbook (Components, Circuits and Applications). Mazda, F.F., Butterworth, London, 1990, 417 pp., US \$79.95.

Turbo C++ Professional Handbook. Ed. Pappas, Chris H., et al., Osbourne McGraw-Hill, Berkeley, Calif., 1990, 773 pp., \$29.95.

Developing Expert Systems for Manufacturing: A Case Study Approach. Kaewert, Julie Wallin, and Frost, John M., McGraw-Hill, New York, 1990, 269 pp., \$46.50.

In-Process Measurement and Control. Ed. Murphy, Stephen D., Marcel Dekker, New York, 1990, 352 pp., \$99.75.

Microsoft Windows Guide to Programming, New for Version 3. Microsoft Corporation, Microsoft Press, Redmond, Wash., 1990, 560 pp., \$29.95.

Elements of Export Marketing and Management—2nd Edition. Branch, Alan E., Chapman and Hall, New York, 1990, 339 pp., \$32.50.

Running UNIX. Woodcock, Joanne, Halvorson, Michael, and Ackerman, Robert, Microsoft Press, Redmond, Wash., 1990, 416 pp., \$24.95.

ISDN: Concepts, Facilities, and Services. Kessler, Gary C., McGraw-Hill, New York, 302 pp., \$44.95.

Microsoft Lan Manager—Version 2. Ryan, Ralph, Microsoft Press, Redmond, Wash., 1990, 576 pp., \$29.95.

Network Modeling, Simulation, and Analysis. Ed. Garzia, Ricardo F., et al., Marcel Dekker, New York, 1990, 392 pp., \$99.75.

APPC: Introduction to LU6.2. Berson, Alex, McGraw-Hill, New York, 1990, 375 pp., \$44.95.

Artificial Intelligence at MIT: Expanding Frontiers, Volumes 1 and 2. Ed. Winston, Patrick H., et al., MIT Press, Cambridge, Mass., 1990, 1200 pp., \$70.

Microsoft Windows Programmer's Reference, New for Version 3. Microsoft Corporation, Microsoft Press, Redmond, Wash., 1990, 1152 pp., \$39.95.

Service Breakthroughs: Changing the Rules of the Game. Heskett, James L., Sasser, Earl W. Jr., and Hart, Christopher W. L., Free Press, New York, 1990, 306 pp., \$27.95.

Origins: The Lives and Worlds of Modern Cosmologists. Lightman, Alan, and Brawer, Roberta, Harvard University Press, Cambridge, Mass., 1990, 563 pp., \$29.95.

Design and Wealth Creation. Schwartz, K. K., Peter Peregrinus, London, 1990, 236 pp., \$65.

Network Management & Control. Eds. Kershbaum, Aaron, Malek, Manu, and Wall, Mark, Plenum Press, New York, 1990, 448 pp., \$89.50.

Managing Complexity in Software Engineering. Ed. Mitchell, R. J., Peter Peregrinus, London, 1990, 263 pp., \$65.

LAN Operations, A Guide to Daily Management. Rhodes, Peter D., Addison-Wesley, Reading, Mass., 1991, 256 pp., \$39.75.

An Introduction to Direct Access Storage Devices. Sierra, Hugh M., Academic Press, San Diego, Calif., 1990, 260 pp., \$44.95.

Real-Time Software Techniques. Heath, Walter S., Van Nostrand Reinhold, Florence, Ky., 1991, 248 pp., \$39.95.

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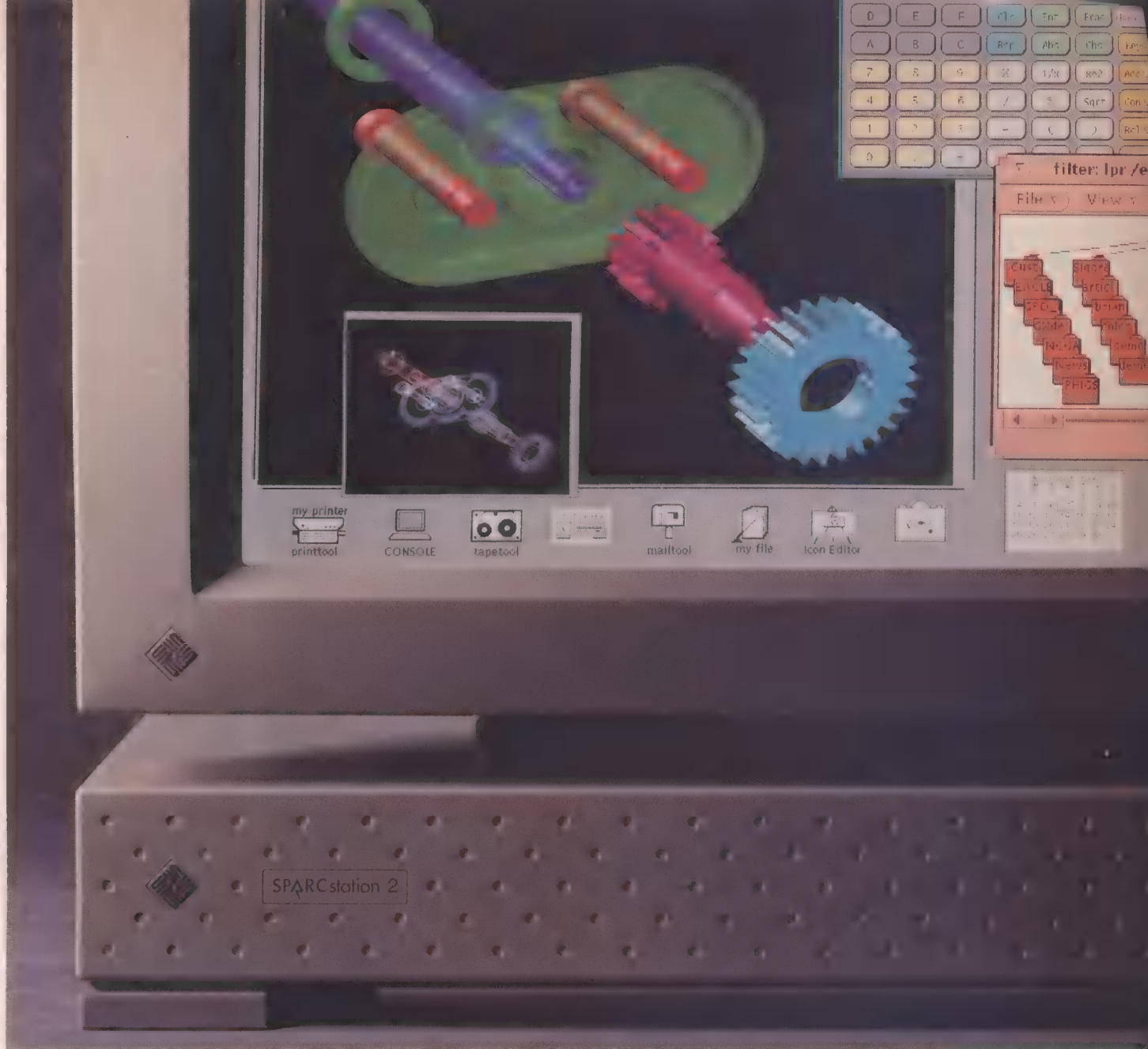
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How U.S. lead in power equipment ended

The innovative partnership that existed in the United States between the electric utilities and the industry's suppliers produced an electric power system that is the model and envy of the world. It also produced manufacturing companies that were world leaders.

Today, many of the great names of this industry—like Allis-Chalmers, ITE Imperial, Moloney Electric, General Electric's large power transformer business, and Westinghouse Electric's transmission and distribution group—have disappeared from the U.S. industrial scene. An understanding of why this happened might contribute to the base of knowledge on which future strategies are developed.

Back some 35 years, the partnership between electric utility and supplier began to unravel. Following the scandal of price-fixing conspiracies by power-equipment suppliers in the late 1950s, and the great "fire sale" of products at low prices that followed, the electrical manufacturing industry began experiencing erratic profits, and embarked on a slow decline in R&D spending.

Concurrently, many electric utilities, which in total then made up the largest sin-

gle industry purchaser of capital goods in the United States by spending US \$4-\$5 to generate \$1 in revenues, took on a short-term buying view. This reversal involved several steps, all of them aimed at driving prices down:

- Encouraging competition from many suppliers.
- Blanket ordering, which sought quotations for a year's worth of anticipated purchases.
- Seeking large, combined product-package bids.
- Encouraging the use of a "sharp pencil" on all bids.
- Buying from the cheapest source.
- Awarding contracts on a winner-take-all philosophy, leading to one winner and several losers.

These approaches were encouraged by state regulatory bodies. They seemed to feel that the consumers' interest was best served by having the lowest initial-cost electric plant, not necessarily one of the highest quality or with the lowest long-term owning cost.

Another factor of no help to the manufacturers is that the plant and equipment needs of the electric utility industry are inherently cyclical. With demand low, fair prices are most needed by the supplier to support its fixed plant and skilled work force. But if the customers' short-term pur-

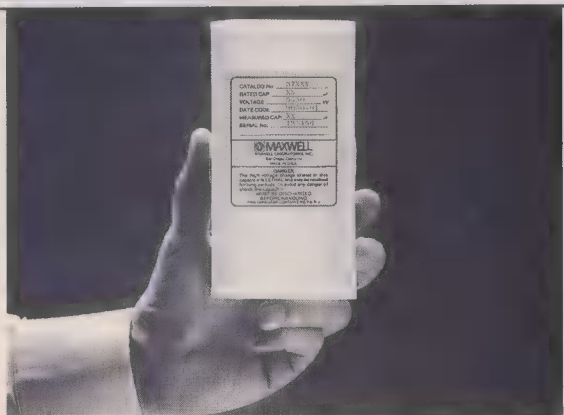
chasing view takes over, prices can be driven to rock bottom. Suppliers scrap for the business and wind up making little profit or even lose money.

And when demand is high, the supplier makes just average profits, unless shortages develop. But if the supplier takes advantage of shortages by charging exorbitant prices, its survival is imperiled because customers remember such opportunistic treatment when conditions return to normal.

When selling into a cyclical market, below-average financial performance keeps pressure on publicly held corporations to reduce their overhead. Both short- and long-term R&D programs are at risk.

Allis-Chalmers was one of the early victims of these profit pressures; its experience was typical. A new chief executive joining in September 1968 concluded that the company could not support the R&D required in the electric products business.

He looked to Europe for joint venture partners which, he indicated, were much further ahead of Allis-Chalmers in R&D know-how and expenditures. He eliminated Allis-Chalmers' R&D division, forming instead an applied engineering operation devoted to short-term developments. A joint venture was begun with West Germany's Siemens AG.



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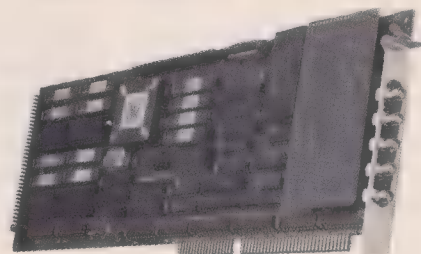
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While such moves were being made, the short-term purchasing view was growing at the electric utilities. This view was nurtured by increasing regulatory and financial pressures, which influenced how the electric utility business was run. More and more, the view of what was best technologically seemed to have less impact on purchasing decisions.

Further, foreign suppliers were penetrating the U.S. market as some utilities, mostly run by the Federal government, opened the door wide. But when U.S. electric-equipment manufacturers turned in the mid-1960s to international markets to help balance their business cycle, they found that markets in developed countries were closed to them and reserved for domestic manufacturers.

The buying view in these countries was generally long term, aimed at supporting R&D and developing the facilities and production skills of their domestic suppliers. Such strong home market support helped manufacturers in these countries become major international suppliers, financially strong and with products at the forefront of technology.

As for markets in developing countries, they were controlled by quasi-cartels of foreign manufacturers that often decided how much of the market each company received. Unlike U.S. suppliers, many of these suppliers had no laws in their home countries prohibiting them from doing business in accordance with a foreign country's shall we say more relaxed business practices and ethics.

The result was that U.S. electric-equipment manufacturers faced unequal competition abroad, wide open markets at home, and unsatisfactory profits in down cycles. Then in September 1973, the oil embargo led to rapidly rising fuel costs, double-digit inflation, lower electric-load growth, and power-generating systems with too much capacity. Demand in the United States for utility equipment began a long downward trend. R&D and product-line development by the equipment suppliers continued to suffer as they worked to downsize their operations and reduce their costs.

This culminated in 1982 with the beginning of the longest down cycle yet for utility capital goods; it lasted about four years. The utilities, faced with pressure to keep rates low, found themselves even further removed from taking the long-term purchasing view.

Concurrently, some utility equipment suppliers began withdrawing from various product lines. Also, firms based outside the United States, with the money and the desire to penetrate what was still the world's largest market for electric equipment, bought partial or controlling interests in U.S. suppliers.

Today we see an electric utility industry in the United States that no longer has a major influence on many of its suppliers. We see an electric-equipment business largely owned or dominated by foreign firms, either European or Japanese. This is particularly so when it comes to heavy technically sophisticated equipment such

as transformers, circuit breakers, dc transmission equipment, insulators, steam generators, and hydraulic turbines.

The principal reason for the present situation is that the U.S. electrical manufacturing industry is playing on a field sloped in favor of its competitors from other developed countries. But even today I believe the trend is reversible for the U.S. players remaining in the electric equipment business if:

- The worldwide playing field becomes more level, including open access to the European Common Market in 1992 and the Japanese market.
- U.S. electric utilities develop policies of evaluating such factors as product performance and quality, technical leadership, and service before and after the sale when making purchases.
- The utilities support with a share of their business the suppliers they decide make long-term contributions to their needs.

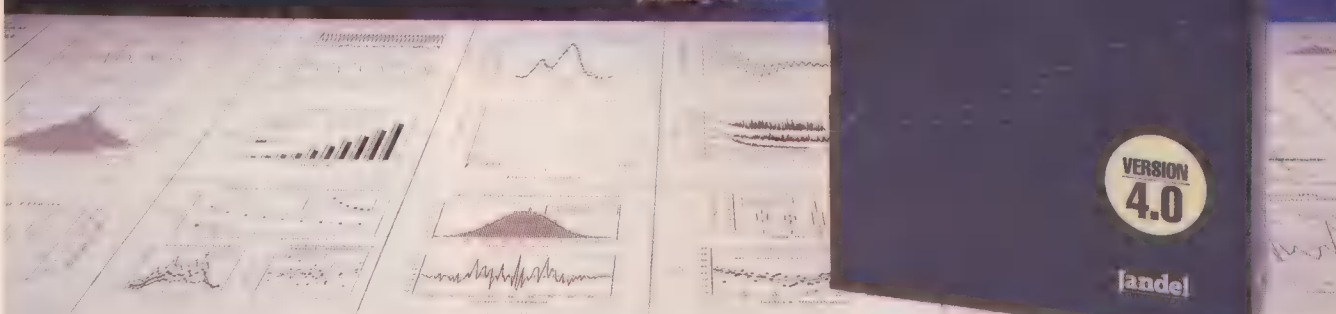
—J. Eugene Watson Jr.

Now retired, J. Eugene Watson Jr. (SM) had a 35-year association with several companies in the electric power equipment field. Included were 21 years at equipment supplier Allis-Chalmers Corp., Milwaukee, Wis., where he was general manager of electric utility marketing; three years as vice president of marketing at an engineering consulting firm, Gilbert/Commonwealth Associates, Jackson, Mich.; and 12 years with Lapp Insulator, Leroy, N.Y., a division of Interpace Corp., where he served as president.

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Computer-on-a-chip: why so long to patent?

On July 17, 1990, the U.S. Patent and Trademark Office, Washington, D.C., granted Patent No. 4 942 516 to Gilbert P. Hyatt for a "single chip integrated circuit computer architecture." The result of a twentysomething-year dialogue with the Patent Office, the Hyatt patent immediately became the subject of numerous front-page articles. For the most part, Hyatt's patent caught people by surprise—and with good reason, as pending patent applications are maintained in secrecy.

Why did it take more than two decades for Hyatt to obtain the patent? And what effect might the patent have?

Answers to these questions can be found in part in the record of proceedings before the Patent Office and the courts.

Most of these documents are patent applications, each of which has three main components: the specification, or technical description of the invention; the drawings that illustrate the invention; and the claims, the numbered sentences at the end that define the invention. Although ■ detailed examination of this material would be well beyond the scope of this column, it's possible to learn a great deal by focusing upon a few key points.

An unbroken chain

The Hyatt patent took so long to issue partly because of repeated filings by Hyatt, who now lives in La Palma, Calif. His patent refers to no fewer than eight separate applications, the first of which was filed in November 1969.

Under U.S. patent law, an inventor can maintain priority over later applicants by filing ■ subsequent application while the previous one is pending. The patent examiner will weigh subject matter common to both applications against only those patents, publications, and other publicly known uses predating the first application.

Without his earlier applications, Hyatt would almost certainly not have received the patent; his claims in the later applications would have been judged anticipated or obvious in view of patents issuing and technical articles published in the 1970s and early 1980s. However, Hyatt did maintain continuity and eventually obtained ■ patent in 1990 based upon applications dating back to 1969.

A second reason for the long-drawn-out examination process was the Patent Office's disbelief that Hyatt's single-chip computer could have been built in 1970.

To begin with, Hyatt offered no evidence that he had actually built the device or that he could have done so at the time. The patent examiner considering Hyatt's second application, filed in 1970, argued that the technical disclosure, principally the specification and the drawings, lacked the details necessary to fabricate the chip. The year 1970 became important because Hyatt ultimately relied upon his second application as ■ reference point for the origi-

nation of the single-chip computer.

The basis for the examiner's concern was that U.S. patent law requires applicants to supply sufficient instruction to enable a person skilled in the field, working from the patent alone, to make and use the patented device or process without undue experimentation. This requirement, referred to as enablement, stems in part from the concept of ■ patent as ■ contract with the Government: in return for a 17-year limited monopoly on the technology claimed, the applicant must adequately disclose the invention.

All the same, patent law does not require the inventor to build the invention: it is sufficient to file a patent application describing and claiming the device or process in question. Even so, the inventor is obliged to provide the information needed to put the invention into effect.

Hyatt's difficulties with the patent examiners arose because he relied upon the general state of the art to establish enablement, instead of incorporating sufficient instruction within his applications. The Patent Office maintained that the state of the art in 1970 was incapable of producing Hyatt's computer on ■ chip, and it refused to grant the patent.

Firm in his belief that the details needed to make his device were well known in 1970, Hyatt appealed the examiner's decision to the Board of Patent Appeals and Interferences, a three-judge tribunal within the Patent Office. Unfortunately for Hyatt, the Board sided with the examiner, stating that the application "merely suggests... a single chip IC implementation... without ever showing how it is done." It concluded that Hyatt's submission was no more than "an invitation to experiment."

No surrender

Unwilling to give up, Hyatt took his case to the U.S. Court of Appeals for the Federal Circuit in Washington, D.C. On June 9, 1988, however, that court affirmed the Board's rejection of the claims, noting that "[b]ecause the filing date is so important in determining patent rights, it is essential that there be no question that, at the time an application for patent is filed, the invention claimed... is fully capable of being reduced to practice...."

Three observations of the Court of Appeals highlight the nature of the opposition Hyatt faced. First, the court stressed that Hyatt had yet to prove that the critical base technology existed in 1970, a more difficult proposition than offering enough technical guidance within the patent application. Second, Hyatt had dealt unsatisfactorily with the Patent Office's concern that input and output pin limitations hampered practical implementation of large-scale integrated devices. Third, he failed to prove that the logical equations disclosed in his application would have made it possible to make the chip in 1970, ■ "key deficiency" in the eyes of the court.

In short, the court felt that Hyatt had "not come close" to satisfying the enablement requirement.

Hyatt filed his last application on June

17, 1988, arguing once again that his disclosure was enabling and that the claims were allowable over the prior art. The examiner remained unmoved and, on July 12, 1989, he rejected all of Hyatt's claims.

Undaunted, Hyatt filed an amendment opposing the rejection, supplemented by another amendment and an affidavit to bolster his enablement argument. On March 9, 1990, and without explanation, the examiner allowed the claims.

Why did the Patent Office finally grant the patent after all these years? Since the examiner is not required to give reasons for allowance, we may never learn the answer. We can only surmise that the last three documents Hyatt submitted were sufficient to overcome the examiner's rejection.

Reading the tea leaves

What ■ some of the implications of the Hyatt patent for the industry?

To exploit the patent, Hyatt basically has two options: license the patent and collect royalties for the term of the patent (it expires in 2007), or bring suit for infringement against companies that manufacture devices Hyatt regards as infringing and seek damages.

Under the licensing option, Hyatt would enter into ■ contract granting permission to those who desire to use the claimed technology, negotiating royalty rate.

If there is an infringement trial, any one of the issues considered during examination of Hyatt's applications could well be taken up again. The question of enablement, although considered at length by the Patent Office and the Court of Appeals, would almost surely be revisited.

Also, even though Hyatt's patent cites a seemingly exhaustive list of 139 prior-art patents and publications, ■ party accused of infringement could search for other prior art in the hopes of invalidating the patent. Alternatively, the accused could argue that the patent is invalid in view of one of the already cited references—a somewhat harder task, since the examiner is presumed to have properly considered this material.

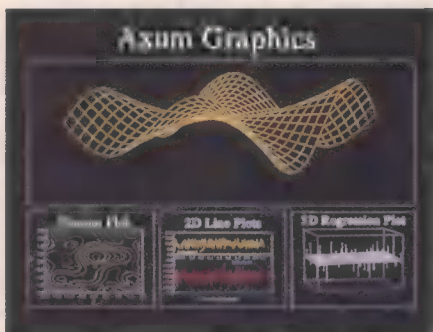
As a procedural matter, the burden of proof on issues of validity rests on the person attacking the patent. Patents are presumed valid and remain so unless and until ■ court or the Patent Office rules otherwise. Thus, the challenging party must first present proof of invalidity. Only then will the burden of carrying the argument shift to the patent owner.

Lesson: leave tracks

A lesson to be learned from Hyatt's long and arduous journey through the Patent Office and the courts is that close attention must be paid to enablement in the drafting of a patent application. If relying upon the state of the art to prove enablement, the applicant would be well advised to incorporate adequate references to journal articles or other patents, rather than leave such matters to chance.

Joel Miller is an attorney at the New York City law firm of Weil, Gotshal & Manges.

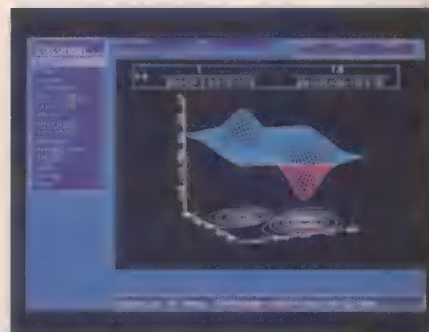
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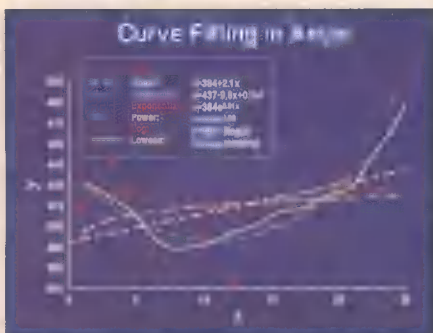
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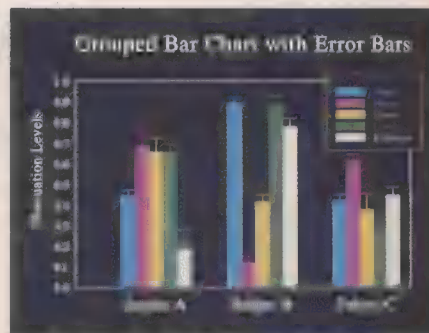
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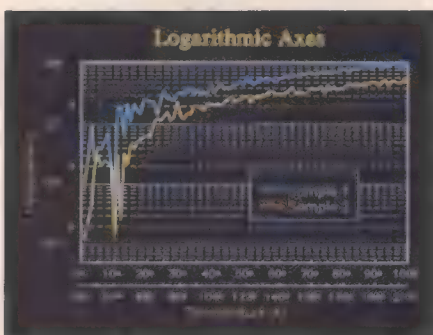
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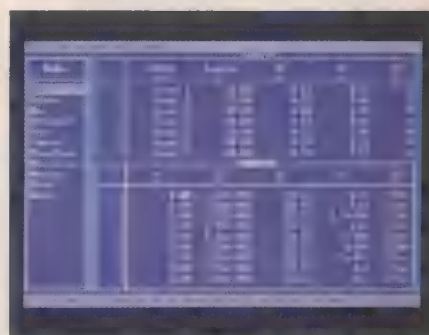


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(continued from p. 8)

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Second International Symposium on Integrated Network Management (IFIP et al.); April 1-5; Crystal Gateway Marriott, Washington, D.C.; Action Motivation, Box 191885, San Francisco, Calif. 94119; 415-392-3751.

Southeastcon '91 (Region 3 et al.); April 7-10; Fort McGruder Inn, Williamsburg, Va.; G. McRee, 525 Virginia Deare Dr., Virginia Beach, Va. 23451; 804-683-4897 (O) or 804-428-0083 (H).

Infocom '91 (COMP, COMM); April 7-11; Sheraton Bar Harbour, Bar Harbour, Fla.; Ken Joseph, Bell Canada, 160 Elgin St., Ottawa, Ont. K1G 3J4, Canada; 613-781-7214; fax, 613-234-1442.

First International Workshop on Interoperability in Multidatabase Systems (COMM); April 8-9; Kyoto University, Kyoto, Japan; IEEE Computer Society Conference Services, 1730 Massachusetts Avenue, N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

Third International Conference on Indium Phosphide and Related Materials (ED); April 8-10; Park Hotel, Cardiff, Wales, UK; Robert Wangemann, IEEE Service Center, 445 Hoes Lane,

Box 1331, Piscataway, N.J. 08855-1331; 201-562-3895.

International Reliability Physics Symposium (ED, R); April 8-11; Caesars Palace, Las Vegas, Nev.; Alfred L. Tamburrino, RADC/ RBRP, Griffiss Air Force Base, N.Y. 13441-5700; 315-330-2813.

Ninth Annual IEEE VLSI Test Symposium (COMP et al.); April 16-18; Bally's Park Place Casino Hotel, Atlantic City, N.J.; Kedong Chao, Johns Hopkins University, APL-Johns Hopkins Road, Laurel, Md. 20723; 301-953-6121; fax, 301-953-1093.

International Symposium on Power Semiconductor Devices (ED); April 22-24; Baltimore, Md.; M. Ayman Shibib, AT&T Bell Laboratories, 2525 N. 12th St., Reading, Pa. 19612; 215-939-6576.

10th International Symposium on Computer Hardware Description Languages and their Applications (IFIP et al.); April 22-24, Marseille, France; Ronald Waxman, Department of Electrical Engineering, Thornton Hall, University of Virginia, Charlottesville, Va. 22903-2442; 804-924-6086.

International Symposium on Subscriber Loops and Services-ISSLS '91 (COMM et al.); April 22-25; Raicongrescentrum Europaplein, Amsterdam, The Netherlands; Paul 't Hoen, PTT Netherlands, Box 39, 2260 AA Leidsehaven, The Netherlands; (31+70) 43 22 33; fax, (31+70) 43 21 40.

International Workshop: Quality of Telecommunications Services and Products (IEEE QAMC); April 23-25; Val David, Canada; V. Seshadri, Room 3J536, AT&T, Crawfords Corner Road, Holmdel, N.J. 07733.

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IEEE/IAS Industrial and Commercial Power Systems Conference-ICPS '91 (IA); May 6-9; Hilton Inn, Memphis, Tenn.; Allan H. Long, Memphis Light, Gas, & Water Division, Box 430, Memphis, Tenn. 38101-0430; 901-528-4859.


Compeuro '91-IEEE Fifth International Conference on Advanced Computer Technologies, Systems, and Applications (COMP et al.); May 7-10; Bologna, Italy; V. A. Monaco, Dip. Elettronica, Informatica e Sistemistica, University of Bologna, Viale Risorgimento 2, 1-40136, Bologna, Italy; 011-39-51-259111.

Power Industry Computer Applications Conference-PICA '91 (PE); May 7-10; Hyatt Regency/ Sheraton, Baltimore, Md.; William Keagle Jr., Baltimore Gas & Electric Co., Electric Test Facility-RBC, Box 1475, Baltimore, Md. 21203; 301-281-3788.

IEEE Pacific Rim Conference on Communications Computers and Signal Processing (Victoria Section), May 9-10; Dr. Pan Agathoklis, Department of Electrical and Computer Engineering, University of Victoria, Box 3055, Victoria, B.C., Canada V8W 3P6; 604-721-8618.

Fourth IEEE Symposium on Computer-Based Medical Systems (COMP et al.); May 12-14; Stouffer Harborplace Hotel, Baltimore, Md.; Jeffrey Lesho, The Johns Hopkins University, Johns Hopkins Road 13-5112, Laurel, Md.

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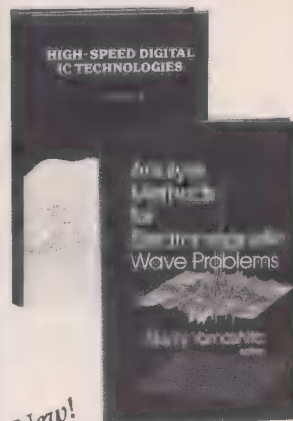
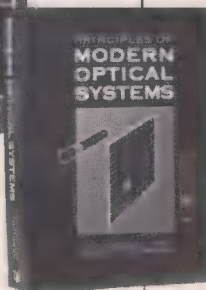
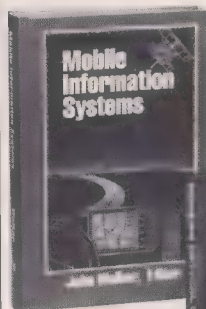
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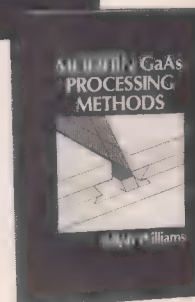
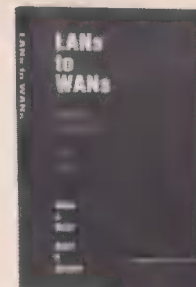
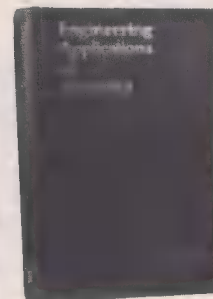
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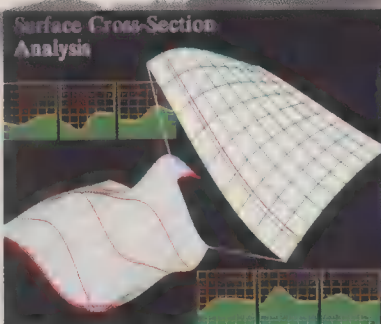


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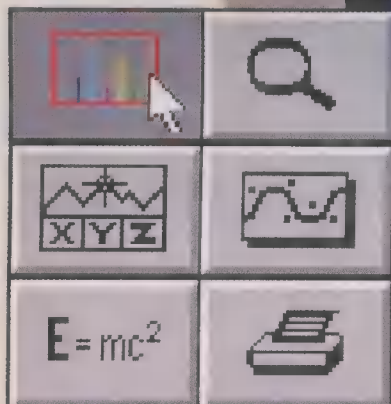
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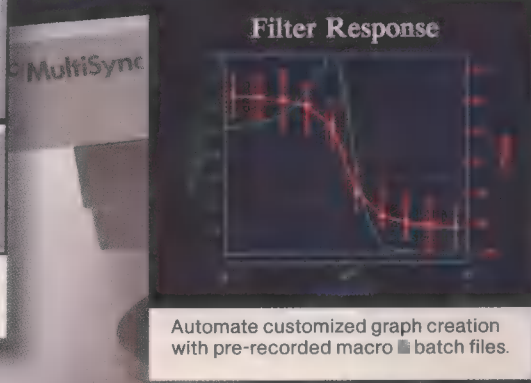
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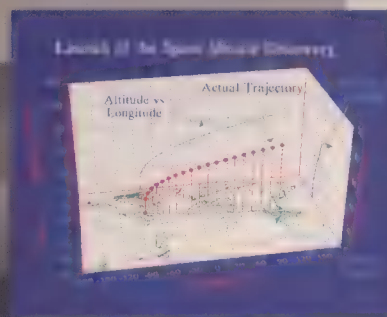
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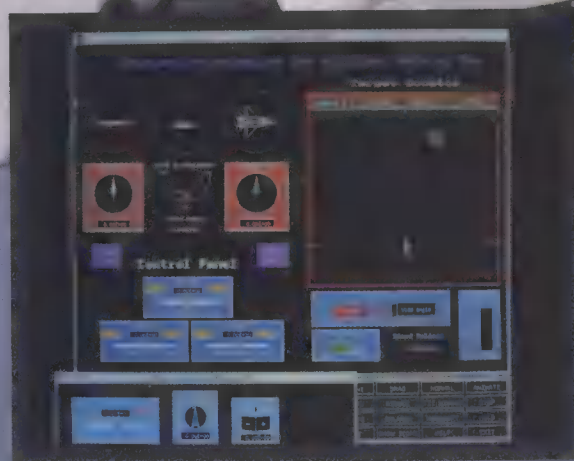
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'Blind' as a bat

Owls, bats, sea mammals, and many other animals move about in total darkness as if they could see. They do it by sending out short bursts of high-frequency sound and listening for the echoes from the objects around them. Their binaural hearing tells them not only the direction from which the echoes are coming, but also the distance to reflecting objects. From this information, they can maneuver with accuracy.

Even blind persons can, by tapping the tip of a cane against pavement and listening to the faint echoes from nearby objects, orient themselves to some degree. Now an ultrasonic echo location system developed by Adam A. Jorgensen of Oakland Park, Fla., which was granted U.S. patent 4 907 136 on March 6, 1990, augments this normal human ability by electronic means.

The device consists of two basic parts. A hand-held ultrasonic emitter projects a stream of ultrasonic bursts; like a flashlight, it can be pointed in any direction. A hearing-aid-like microphone and receiver mounted behind each ear amplifies and converts ultrasonic echoes down in frequency to audible echoes. It also adds an artificial variable delay so that users can better distinguish between the echoes reflected from objects less than 2 meters away.

In order for a user to clearly sense distances from the received echoes, the emitter issues a reference pulse that sounds like a muted "pop" each time it sends out a burst of ultrasonic pulses. The pop is followed by the delayed echo. The sooner the echo follows the pop, the closer the reflecting object is to the user. If there are several objects within the emitter's "field of view," the pop will be followed by several echoes.

The user can, by pointing the sound emitter in different directions and listening to the echoes, pick out and sense the position, size, and nearness of objects of interest, just as a sighted person entering a dark room with a flashlight may swing the light beam in different directions to get a picture of the room and its contents. In addition, as with some flashlights, the field of view can be either widened or tightly focused.

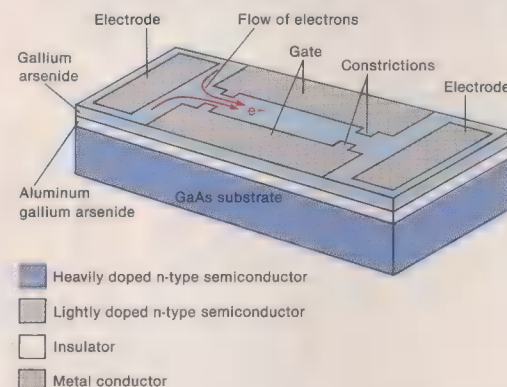
The system is sensitive enough to retain the acoustic profiles of objects, thereby allowing an experienced user to discern something about their shape and texture. For example, echoes of footsteps on a sidewalk alongside a slatted fence sound distinctly different from the echoes from a solid wall and both sound different from the muted echoes from a soft surface such as a curtain.

Jorgensen, along with his brother Otto, has built the system as a preproduction prototype for testing and evaluation by vision-impaired and blind volunteers. The two brothers—both engineers—have submitted a test plan to the National Eye In-

stitute in Washington, D.C., which should complete its evaluation of the proposal early this year.

A single-electron transistor

In what could lead to a new class of electronic devices, researchers at the Massachusetts Institute of Technology (MIT), Cambridge, along with a colleague at IBM Corp. have fabricated a radically new kind



of transistor that turns on and off with the addition or subtraction of a single electron.

Physics professor Marc A. Kastner and post-doctoral researcher Udi Meirav, both working at MIT's department of physics, and research scientist Shalom J. Wind of IBM's Thomas J. Watson Research Center, Yorktown Heights, N.Y., reported their development in the Aug. 6 issue of *Physical Review Letters*.

In some respects, the experimental device is similar to an ordinary silicon field effect transistor. It consists of a thin layer of lightly doped gallium arsenide grown on top of a thin layer of insulating aluminum gallium arsenide, which sits on a GaAs substrate heavily doped to have an excess of electrons [see illustration]. A metal electrode is fixed at each end of the top GaAs layer. When a voltage is applied between the GaAs substrate and the top GaAs layer, a current proportional to the voltage flows between the two metal electrodes.

But the MIT/IBM device also has a unique feature: a pair of metal strips on top of the GaAs layer that act as a gate between the two electrodes. When a voltage is applied to the gate, the electrons are forced into the narrow GaAs channel lying beneath the gap between the gate's two metal strips, confining current flow to one dimension.

Furthermore, by adding two points at each end of the gate, the researchers further constricted the channel, creating an isolated segment of a fixed length. This constricted gate structure gives rise to the transistor's unique behavior: as the voltage is increased, the current between the electrodes does not go up smoothly, but oscillates with a period corresponding to the number of electrons in the segment. Each time an electron enters the channel, it forces the current to go up and down in a

complete cycle, turning the transistor on and off. In effect, the addition or subtraction of a single electron controls the transistor's state.

Kastner and his colleagues also discovered that by adjusting the voltage, they can control the precise number of electrons in the segment—and thus determine whether the device is off or on. If there is an integer number of electrons, they act together to repel any other electrons from entering the circuit, and the current is essentially zero. In fact, when the average number of electrons in the segment is anything except halfway between two integers, no current flows.

For example, if there were an average of 10.5 electrons in the segment, current would flow, but would not if there were 10.4 electrons. (An average of 10.5 electrons means that half the time there would be 10 electrons, and half the time there would be 11 electrons; an average of 10.4 electrons means that 40 percent of the time there would be 10 electrons

and 60 percent of the time there would be 11 electrons.) According to Kastner, an average change as small as 0.1 electron can alter the current passing through the channel by a factor of 100.

Kastner speculates that it may be possible to create a multistate transistor that would turn on and off many times with increasing voltage, instead of just once, as in a standard transistor. But to be practical, that would require the transistor to work at much higher temperatures than the experimental device, which functions only at 1 K.

Preliminary results suggest that the device may work at higher temperatures, but only if it is made much smaller: the temperature at which it works appears to be inversely proportional to the electron-flow area of the device.

Although commercial applications are not likely for some time, the researchers expect that further inquiry into the transistor's behavior may lead to new physical understanding of quantum mechanical processes.

Simulating indoor cellular radio

The boom in cellular radio communications is spurring both manufacturers and service providers to look to new systems that will accommodate many more users than traditional systems, as well as give each user versatile communications capabilities with a low-power, lightweight terminal. One obvious new application then would be inside buildings, for communications ranging from telephone conversations to data transfer over wireless modems.

Although many researchers have studied the ways in which radio signals prop-

(continued on p. 55)

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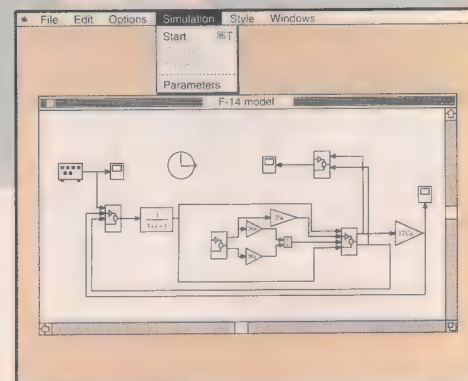
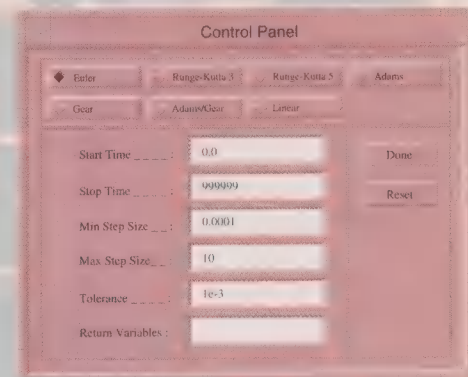
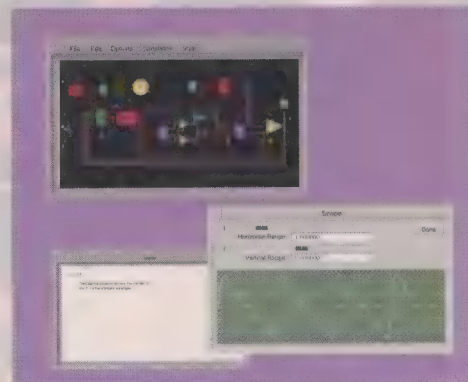
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(Top) Use the Scope block to see the "real-time" response of this F-14 model during the simulation; (Center) Specify simulation parameters via dialog boxes or the MATLAB command line; (Bottom) SIMULAB takes full advantage of the X/Motif and Macintosh windowing systems.

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Fixed-price development

On Jan. 7, the Pentagon canceled the A-12 program. The U.S. Navy Avenger attack plane was to be a carrier-based, faster version of the A-6 Intruder, with radar-evading, all-weather, night-fighting capabilities.

McDonnell Douglas Corp. and General Dynamics Corp. bid jointly to develop the aircraft at a fixed price of \$4.8 billion and were awarded the Pentagon contract in 1988. The contractors have already spent more than \$4.8 billion and have yet to build a prototype.

The cancellation was premised on the failure to "design, develop, fabricate, assemble, and test the A-12 aircraft within the contract schedule and to deliver an aircraft that meets contract requirements." Defense Secretary Dick Cheney said, "This program cannot be sustained unless I ask Congress for more money and bail the contractors out, but I have made the decision that I will not do that." The Government has reimbursed the contractors for \$1.2 billion, and estimated that the revised cost of completing the contract would have totaled \$7.5 billion.

The following facts seem not to be in dispute:

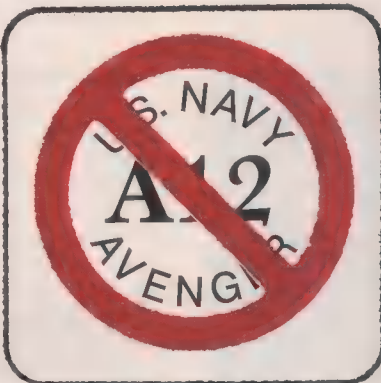
- The complex plane would have broken new ground in characteristics and capabilities.
- The Pentagon believes the United States needs such a plane.
- The Pentagon required a fixed-price bid for the contract.

But the cancellation raises the following questions:

- Was the fixed-price development concept realistic, particularly in view of the history that com-

plex, advanced-technology projects have built-in uncertainties that virtually guarantee delays and added costs?

- Isn't the military customer in effect a co-manager of complex development programs and, as such, equally responsible with the contractor for estimating development costs and endorsing revisions as appropriate?



- If so, what is the best mechanism for cost containment—that is, for protecting the taxpayers' interests?

- Is the Pentagon behaving like a petulant board of directors who would penalize a CEO for operating as they instructed him to, even though the new instructions were unrealistic? Or will it take a constructive role in changing the procurement system so that it doesn't pit customer against contractor in a no-win situation?

Questions relating in particular to the A-12 contract cancellation include:

- Since a plane of this type is needed, how will it be procured? Will the work done for the A-12 be salvageable? Would McDonnell Douglas and/or General Dynamics be willing to bid if and when a new request for proposals is issued? Would others who bid on the A-12, like Grumman Corp., be ready to bid again?
- What would be the cost of reassembling a team to restart a project similar to the soon-to-be-defunct A-12 project?
- What will be the impact on taxpayers in social costs of the laid-off workers?

In the end, when an equivalent of the A-12 is fielded, will it have cost taxpayers more, and will it be delivered later, than if the A-12 program had been continued?

On-line transmission

Authors and reviewers can now communicate with *IEEE Spectrum* through a computer bulletin board. Manuscripts, reviews, and letters to the editor may be transmitted directly to *Spectrum* via Macintosh, IBM PC or compatible, or any computer system with access to a modem.

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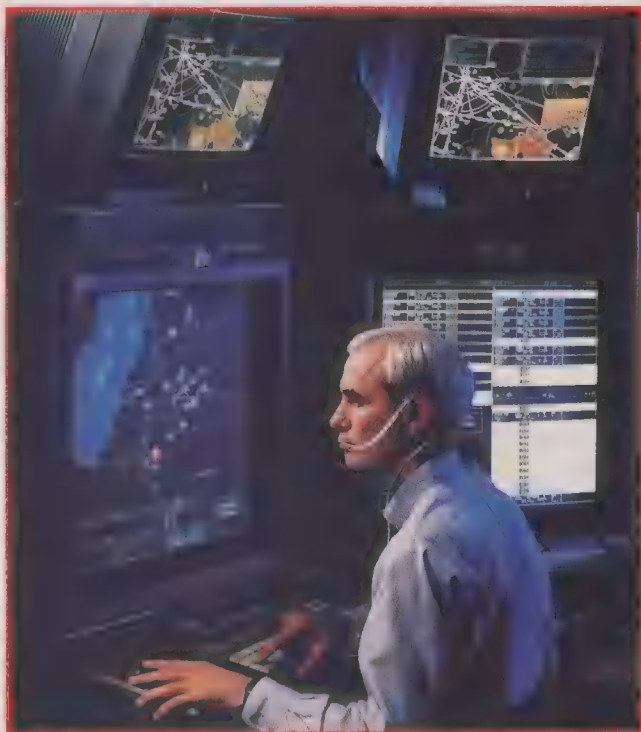
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—Donald Christiansen

Improving the world's largest, most advanced system

Steady growth in air travel strains U.S. efforts to fully implement massive short- and long-term technological upgrading



With the new automation aids that engineers and users are devising, future ground controllers will be more like strategic managers than harried tacticians.

If the world seems to be getting smaller, one reason is that air travel—international and domestic, for passengers and freight—is soaring. The pace is so fast that it is outstripping the capacities of runways and air traffic control systems in the United States, Europe, and the Far East. Consequently, in many places the jet age is becoming one of congestion, delays, higher ticket costs, and possibly diminished safety, according to a recent report by the National Research Council, Washington, D.C.

However much its air traffic control operations are criticized, the United States has long had the most technologically advanced and the largest system of airports in the world. This month, *IEEE Spectrum* focuses on the U.S. system.

It now carries about 1.3 million travelers a day to domestic and international destinations—up from about 468 000 passengers in 1970. Similarly, during that period the number of big airliners grew from 2118 to more than 3500. Within that timeframe, unfortunately, the combination of concrete and electrotechnology to manage the traffic growth has not changed much.

The number of accidents and near-misses (to the extent they

can be reported) appears not to have increased proportionately, and has even dropped or held steady since 1984, according to William Pollard, the top air traffic operations official in the Federal Aviation Administration (FAA), Washington, D.C. If passengers seem to squirm in their seats more often these days, it is probably because of the increased delays (more than 400 000 in fiscal 1990) and the perception of a system not totally in capable hands.

One of the nation's largest civilian technology programs, the FAA's airspace modernization plan, was wrought in the early 1980s, when deregulation and a nationwide controllers' strike had twin impacts on travel. But for a number of reasons, technological upgrading has been relatively slow. With projections for early next century of 2.5 million passengers flying each day and nearly 5000 airliners—plus smaller craft—sharing the skies, pilots, controllers, and others are clamoring for remedies.

The first part of *Spectrum's* report, by Senior Editor Tekla S. Perry, examines near-term improvements in the air traffic control system and addresses concerns over whether these changes will be comprehensive and made quickly enough to keep up with traffic growth. For instance, new mainframe computers were installed in the 20 U.S. *en route* centers just as several of the busiest locations had begun to push their computing systems to their maximum capacity. However, new technology planned for airport towers and approach control facilities has been delayed, and the FAA is scrambling to improve existing computer systems to prevent capacity overruns.

In Part 2, longer-term solutions to air traffic management are examined by Senior Associate Editor John A. Adam. Global networks of satellites for communications, navigation, and surveillance, for example, may upstage ground radars in the next century. Greater capability in the cockpits, including collision avoidance systems and flight computers with extensive libraries; better weather prediction and information transfer; and plans for artificial intelligence in the system also are reviewed.

For the final section, *Spectrum* gathered a forum of 15 people, all well-versed in air traffic control operations. They share opinions on top priorities for safe and accessible skies.

1. A system-wide upgrade races to replace two-decade-old equipment

On Dec. 3, 1990, a Northwest Airlines jet accelerating on an airport runway toward takeoff in Detroit collided with another Northwest plane that was lost while taxiing in the heavy fog. Eight people were killed. A pilot had made a deadly mistake. But air traffic controllers had no way of preventing such an error, for

Tekla S. Perry Senior Editor

no radar observes Detroit's runways. Instead, the safety of planes on the runways depends entirely on people. When they are not perfect, disaster can strike without warning.

The Federal Aviation Administration (FAA), the Washington, D.C.-based Government agency in charge of U.S. airports and airways, has been aware of the danger of runway crashes, and in 1985 commissioned the design of a state-of-the-art radar system to observe runways. Today, 12 busy airports, Detroit not among them, have an earlier version of such radar, but the technology dates from the late 1950s and is difficult to use because of clutter caused by buildings and rain. Installation of the new radar remains behind schedule. According to the original timetable, Detroit was to get its surface radar by March 1991; now it may have to wait until late 1992.

Such contradictions permeate the entire U.S. air traffic control system. The FAA has recognized that control can be made much safer (a welcome change from the days when Congressional mandates were requested to jolt it into action). The agency has commissioned a system-wide redesign—radars, radios, computers, workstations, and software—with top to bottom changes to increase controller productivity, equipment reliability, and safety. Joseph M. Del Balzo, FAA executive director for system development, told *IEEE Spectrum*: "We resolved never to find ourselves again in the situation we were in in 1981, with an obsolete system that resulted from years of neglect."

But most of the planned projects have been delayed for a number of reasons. A National Airspace System Plan (recently renamed the Capital Investment Plan), which was to be completed in 1991 and cost US \$12 billion, will, at best, be completed in 2002 and cost over \$20 billion, including added projects, according to the U.S. General Accounting Office (GAO) in Washington, D.C. On the plus side, all but two of the original 90 plan projects are under contract, and over 30 percent are completed.

In the meantime, traffic limitations imposed to keep the skies safe have resulted in takeoff and landing delays, particularly in bad weather. Indeed, in the summer of 1986, delays got so bad that an Eastern Airlines pilot awaiting takeoff clearance in Atlanta, Ga., walked off the plane in frustration. In 1990, some 400 000 flights were delayed 15 minutes or more—and that figure would be higher, but airlines recently revised their schedules to allow more time before listing a flight as "delayed" to assist passengers in planning trips, though such revisions mask degradations in system efficiency. A typical flight from New York to Los Angeles was scheduled to take about 5½ hours in 1987, according to the Official Airline Guide; it is scheduled to take 6

hours today.

The FAA air traffic control system, a network of computers, radios, and radars designed to keep aircraft safely separated as they traverse the skies, is divided into four basic types of facilities: *en route* centers, terminal radar approach control facilities (tracons), towers, and flow control. The centers handle planes in transit and approaches to some airports, and control the highest altitudes. The tracons handle planes in the lower altitudes as they approach or leave busy airports. The towers issue takeoff and landing clearances and control planes on the ground, based on information from flow control about system capacity. All rely heavily on computer technology ranging from antique to near state of the art. Every commercial aircraft in U.S. airspace (all required to file flight plans) and every private plane that has filed a U.S. flight plan places itself in the hands of this system [Fig. 1].

Most of the computing power that helps controllers guide planes is located at the *en route* centers and tracons. The 20 *en route* centers achieved a quantum leap in computer capacity: in 1988, the last of the aging IBM Corp. 9020 computers (a 1960s' technology) were replaced by IBM 3083 computers. This upgrade, which involved a "re-hosting" of 2 million lines of assembly and JOVIAL code (moving it from the old computers to the new ones with minimal changes), increased the maximum number of planes each center could track from 400 with the 9020s to up to 3000 with the 3083s (depending on new functions added to help controllers), and speeded the response by about 10 times.

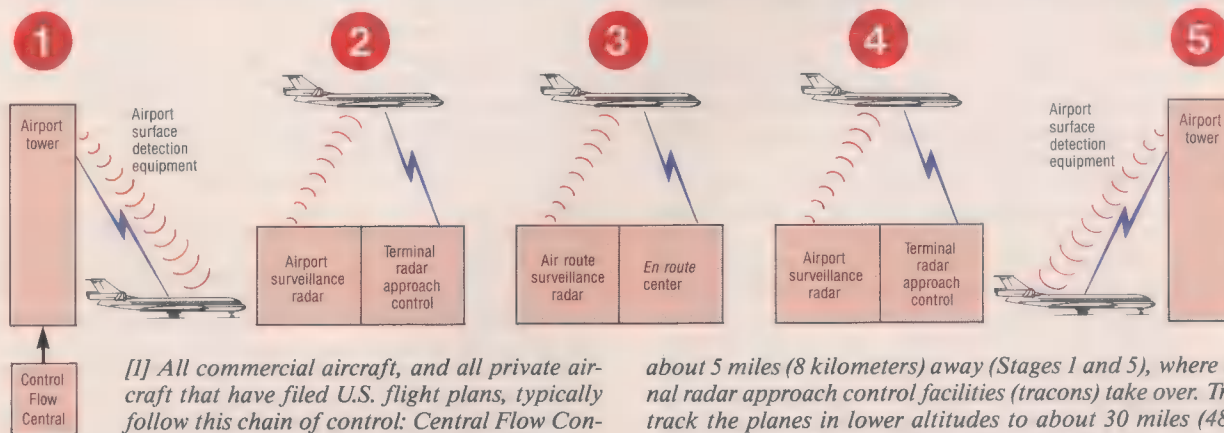
This new hardware was a boon to the two or three busiest centers, which had begun to see noticeable slowdowns in computer response at peak travel times. The New York *en route* center, for example, was approaching 100 percent capacity during some peak periods, according to the FAA's Del Balzo. At somewhere over 90 percent capacity, the computer system begins losing track of planes and drops their notations from the controllers' screens. "To my knowledge, that was not a significant problem [when we replaced the hosts]," Del Balzo told *Spectrum*, "but had we not replaced them, we would not be able to handle today's traffic."

Enhanced functions

The new host computers can do more than just identify planes. One function implemented on them is called Mode C Intruder: while the old computer systems were able to alert controllers when two controlled aircraft were on a collision course, the new system can call the alert even when one of the aircraft is not under air traffic control, as long as both carry Mode C transponders.

Air traffic control on a typical commercial flight

Source: Office of Technology Assessment



about 5 miles (8 kilometers) away (Stages 1 and 5), where terminal radar approach control facilities (tracons) take over. Tracons track the planes in lower altitudes to about 30 miles (48 kilometers) from an airport (Stages 2 and 4), then transfer control to en route centers (Stage 3), which each handle a different region of airspace, passing control from one to another as borders are reached.

(Such a Mode C Intruder feature might have prevented a 1986 crash over Cerritos, Calif., between an Aeromexico jet and a private plane not under FAA control.)

Reliability is an area where the new host computers are far ahead of their predecessors, according to William Carson, general manager of the air traffic control program for IBM Corp., the contractor for the hosts. In the first year of operation, none of the 3083 host computers has had more than 10 seconds of downtime in more than 50 000 hours of operation, he told *Spectrum*. Statistics for the 9020 computers are not available.

These reliability figures may not paint a completely rosy picture, however. According to Warren Zentz, regional vice president of the Professional Airways Systems Specialists (PASS), the Washington, D.C.-based union representing the technicians who maintain air traffic control equipment, technicians are not being trained on hardware recovery. Maintenance was to be contracted out until the technicians learned the new system, but no training courses have started. "School is still out on the new hosts," Zentz told *Spectrum*. "If they begin failing in five years, we don't know whether Humpty Dumpty is going to be able to be put back together again."

FAA officials, IBM executives, and controllers alike agree that replacement of the host computers, completed in June of 1988, went surprisingly smoothly. The project was only six months late. The new host was run in parallel with the old 9020 computer at the Seattle *en route* center for about three months until controllers and technicians were confident that it would not fail. Then a switch was flipped and the 3083 took over permanently. The transition at the other 19 *en route* centers took less time because fewer problems needed to be worked out, said IBM's Carson.

According to a survey by the GAO, two out of three controllers in the 20 *en route* centers saw the introduction of the new host computers as a positive factor in helping them do their jobs. But controllers at about 200 tracons and airport towers are struggling without such a technology infusion.

The 1983 National Airspace Plan called for completion of the Advanced Automation System (AAS) by 1994 [see part II, special report]. As part of the AAS, tracon facilities would merge with *en route* centers and receive similar new equipment. Because of that scheduled merger, no new equipment purchases for tracons were planned. But now few people expect the AAS to be completed before the year 2000. Consolidation plans are up in the air. And concerns are being expressed over whether it will be possible to relocate large numbers of controllers—and whether Congressmen will be willing to let a large Government employer leave their districts. Also discussed is whether consolidation will hurt system reliability and make it more vulnerable to sabotage.

Another major concern is that the tracons serving large airports are badly strapped for computing capacity. They use a system called automated radar terminal system (ARTS) III, based on Sperry military computers, a 1960s' design that the company stopped manufacturing in the 1970s. Each of up to eight 32-bit processors in this dated system can have up to 256K bytes of RAM and process data at a rate of 0.5 million instructions per second (MIPS). In contrast, today's PCs typically have 4M bytes of RAM and operate at 3 MIPS.

In the late 1980s, the ARTS III capacity problem was becoming critical. Larry Barbour, chairman of the safety committee for the National Air Traffic Controllers Association (Natca), Washington, D.C., and a controller at the Washington center, told *Spectrum* that Natca had worried about the capacity problem for years. Controllers at the Dallas/Fort Worth tracon had been losing data blocks—which identify the aircraft, its destination, altitude, speed, and direction—as well as finding data blocks attached to the wrong radar return at peak travel periods. The controllers predicted that in the fall of 1989, when the University of Texas vs. the University of Oklahoma football game brought a flood of private aircraft into the Dallas area, the ARTS computer would hit maximum capacity and fail. It did. "All data blocks were lost; controllers were working with only primary targets [un-

labeled radar returns]," Barbour told us.

In 1988 and early 1989, the New York tracon ARTS, which is an enhanced configuration that serves three major airports from one location, was running at over 90 percent capacity regularly, and technicians used home-grown computer programs to selectively delete information about planes outside the control area and prevent the system from dropping planes at random.

These and other computer capacity shortfalls at some large, busy tracons are "impairing controllers' ability to maintain safe separation of aircraft," the General Accounting Office reported in July 1989.

In September 1989, following a plan set in late 1988, the FAA issued a \$45 million contract to Unisys Corp., Blue Bell, Pa., to reopen ARTS production and add memory and processors to the ARTS computers. It added \$75 million to the ARTS III upgrade contract in 1990 and has begun contracting for upgrades to ARTS II, a system at smaller airports that uses a single 16-bit processor. As part of the ARTS III upgrade, Unisys this year added solid-state memory (the original ARTS installations used magnetic-core memory) to the tracons in Chicago and Dallas, increasing processing power by 25 percent, the maximum.

In New York City, along with solid-state memory, Unisys installed additional I/O processors, separate display processors to take over the chore of refreshing the controllers' screens, and new displays that reduce flicker and can display digitized radar returns. These changes nearly doubled the capacity of the system, to 2800 planes tracked. Also in 1990, Unisys finished a rush project to upgrade computer memories at the nine other busy U.S. airports, and all ARTS sites will receive some level of upgrade by 1994. In addition, the Mode C intruder alert will be added to ARTS systems, starting in New York in 1991.

Though this part of the ARTS upgrade was handled relatively quickly, a GAO report last September criticized this plan, indicating that it might not be until 1998 that all the necessary upgrades

Defining terms

Airport surface detection equipment (ASDE): a digital radar system used to track planes and vehicles on airport runways and up to 200 feet in altitude. Unlike previous surface radar systems, ASDE provides clear images in bad weather.

Automated radar terminal system (ARTS): a multiprocessor computing system used at terminal radar approach controls and airport towers, based on Sperry Univac 1140 computers. Various configurations, differing in size of memory and number of processors, exist at different facilities; the largest, ARTS III, is installed at the New York tracon.

Category 3: a term describing the worst weather situation for landing, when visibility is obscured at all levels. A Category 2 occurs when visibility is acceptable up to 1200 feet under a ceiling of under 100 feet. A Category 1 has even better visibility conditions.

Differential GPS: a technique using the global positioning satellite (GPS) network, where a fixed ground GPS receiver (for precisely known three-dimensional coordinates locally) determines corrections to be applied to local aircraft (or other mobile units) using satellite guidance.

En route control center: one of 20 U.S. air traffic control facilities that control aircraft traveling at altitudes above 18 000 feet.

Instrument landing system (ILS): a radio beacon system forming a straight pencil beam from the runway that planes can follow from 5 to 7 miles (8–13 kilometers) away. An alternative is a microwave landing system.

Microwave landing system (MLS): a microwave system that creates a fan-shaped beam over a wide volume of airspace so planes can use various approaches to a runway during bad weather.

Terminal radar approach control (tracon): one of 18 U.S. air traffic control facilities that are responsible for areas designated as terminal control areas, the exact size of which differs depending on the facility, but typically extends to about 30 miles (48 kilometers) from the airport tower.

[2] Radar that can penetrate bad weather to track aircraft and vehicles on the ground is under development by Norden Systems Inc., Norwalk, Conn. Called airport surface detection equipment-3 (ASDE-3), this new radar is currently being tested at the Greater Pittsburgh International Airport.

are installed. The GAO has also questioned whether the planned upgrades can handle the processing requirements of the new Mode C intruder feature. The FAA has responded that it will meet these requirements. According to Del Balzo, for the longer term the FAA is considering bringing entirely new computer systems into the tracons and towers.

Tower of Babel

One problem nowhere close to being solved is that of too many pilots communicating with a controller on one radio frequency—with pilots often unable to break through even in an emergency. About 70 percent of aircraft accidents involve some form of communications degradation (some are radio problems, some are human misunderstandings), said Marvin Smith, a professor at Embry-Riddle Aeronautical University, Daytona Beach, Fla.

As an interim measure to reduce the crowding of frequencies, the FAA began in 1989 to use a service called aircraft communications and reporting system (Acars) to transmit digital data about predeparture clearances (times to start engines, push back from gates, and so on), instead of requiring controllers to read clearance information on the radio. Acars, run by Aeronautical Radio Inc. in Annapolis, Md., is a commercial service that airlines use to send to screens in the cockpit information about weather at a destination, connecting flights, and the like.

According to the FAA's Del Balzo, at the three airports that have moved clearance data to Acars (Chicago, Dallas/Fort Worth, and San Francisco), pilot-controller communications have been halved. By summer, the FAA intends to introduce this program at some 20 airports and may transfer other non-time-critical information (like weather reports) to Acars.

Long-term solutions are in view, such as increasing the number of frequencies by reducing the spacing between channels (this may take decades to achieve) and developing digital data links (scheduled for initial delivery in 1993) that will transmit information from controllers' computers directly to pilots' computers.

Nationwide, the reliability of radio transmitters and receivers has improved somewhat in the past few years as solid-state equipment has replaced the last of the vacuum tube radios. But technicians and controllers told *Spectrum* there are still problems with radio control equipment. Much of it dates from the 1960s. The FAA has awarded a contract to provide modern control equipment throughout the system and, as an interim measure, some FAA regions have installed some new equipment. But the older equipment still causes loss of communications fairly frequently.

AT&T Federal Systems, Silver Spring, Md., and Harris Corp., Melbourne, Fla., are currently competing for the contract to design and build a new system, called the voice switching and control system (VSCS), which will replace the radio communications switches at *en route* centers nationwide, and will interface with the new controller workstations being designed. The VSCS will be a computer-controlled system for both ground-to-ground and air-to-ground communications; controllers will be able to change communications channels from their workstations. VSCS will also be able to assign any frequency to any workstation, so a controller can easily reconfigure the airspace under his or her command; current switching systems at tracons and centers are hardwired to individual consoles.

According to the 1983 National Airspace System Plan, VSCS was to begin being installed in 1989. In a 1989 planning document, the contract was to be awarded by the end of that year and the first system installed in 1993. The contract has yet to be awarded. According to a 1989 GAO report, the FAA and the two prototype development contractors had "underestimated the amount of work needed to meet system requirements," and continue to

Norden Systems Inc.



have difficulties designing hardware and software that meet the specifications. One difficult specification is the 99.99999 percent availability required—less than 4 seconds of downtime annually. According to AT&T, no commercial switching system in the world can reach less than 3 minutes of downtime annually.

Radar replacements

In the wake of the 1986 Cerritos, Calif., Aeromexico crash, much attention turned to the vacuum tube radar that had been observing that piece of sky since its installation in the 1960s. Reports from Professional Airways Systems Specialists indicated that the radar had been performing far below par at the time of the crash, and could have missed a few returns.

Today, Del Balzo told *Spectrum*, the FAA is "pretty much out of the vacuum tube business." Many components in the oldest radars have been replaced by solid-state equipment. However, until recently these replacement radars relied on 1970s' analog technology, which paints smears on controllers' displays, not exact locations. The first digital radar systems, which place distinct dots on the controllers' displays, were installed in 1989. The first airport surveillance radar-9 (ASR9) went into Huntsville, Ala. Currently, 20 ASR9s are operating, and 24 are scheduled to start up this year.

In addition to locating aircraft more precisely, the ASR9 eliminates extraneous returns on the radar screen (from mountains or tall buildings), can display six severities of weather, and can track aircraft through precipitation (previously, controllers would try to route aircraft around precipitation to avoid losing track of them). The radar system is the first to use Doppler processing to distinguish moving from stationary targets. Each ASR9 unit has two channels, one operating and the other on standby. If the operating channel fails, the system switches automatically to the other.

A key advantage of the ASR9 radar over previous generations is that it can operate unattended, said John Tymann, general manager of the Airspace Management Systems Division for Westinghouse Electric Corp., Linthicum, Md., the contractor supplying the radar. Previous radars required the daily presence of technicians to monitor and fine-tune them. In contrast, each ASR9 can be monitored remotely, and is designed to have only 4 hours of downtime annually.

As has become typical for air traffic control system upgrades, the ASR9 development fell well behind schedule: in 1983, the FAA expected to have 124 systems installed by the end of 1989; now those systems are scheduled to be completed by the end of 1993. Much of the delay was caused by the complexity of the 150 000 lines of PLM code that needed to be developed, Tymann said, particularly the code controlling moving-target detection and remote monitoring. Also, the first system installed had unexpected problems in the field, he said, because of inadequate training

[3] Terminal radar approach control facilities (tracons) use 1960s' vintage Sperry-Univac-based systems, called automated radar terminal systems (ARTSs), to track flights. Similar round, monochrome, radar displays are used in the en route centers, where they interface with modern IBM computers. The New York tracon shown has the most advanced ARTS system, ARTS IIIE.



Bob Klein, Unisys Corp.

of technicians and confusing operational procedures, but these were quickly fixed.

From the controllers' viewpoint, the ASR9 radar is not perfect. They complain of blind spots in some locations as well as noise, but they expect these problems to be solved soon. Perhaps the biggest problem is not due directly to the ASR9 but to the overloaded tracon computers. The ASR9s can spot many more targets than the older radars they are replacing—and this increases the overload on the computers that must process the radar data.

The ASR9s, with a maximum range of 60 miles (100 kilometers), are intended for use only by approach and tower controllers. Most of the long-range radars (the air route surveillance radar, or ARSR) that are used by the *en route* centers have had their vacuum tubes replaced by solid-state components. The next generation of long-range radar technology—the ARSR4—is currently being designed by Westinghouse, and units are scheduled to be installed in the mid-1990s.

Plans for a new radar to track planes on the surface—the type of system that could have helped the ground controller in Detroit realize he had a lost pilot—are back on the drawing board.

Today, 15 airports, including New York City's Kennedy, New Jersey's Newark, and Washington, D.C.'s Dulles, use airport surface detection equipment (ASDE) 2. Designed in the 1950s, this system has difficulty detecting aircraft through precipitation; it is noisy, its vacuum tube components are not very reliable, and it is hard to repair. Still, controllers say, it is better than nothing.

A contract to produce 30 new digital ASDE systems—ASDE3—was issued to Norden Systems Inc. of Norwalk, Conn., in 1985. According to the original schedule, the first ASDE3 was to have begun service in 1988, the 30th in 1990. The first ASDE3 actually began being tested at the Greater Pittsburgh International Airport in 1990 and is expected to be fully operational by the end of 1991. (Pittsburgh, a busy hub, desperately needs surface radar because the control tower is very high and is often separated from the ground by a cloud bank.) Under an expanded contract, 32 systems will follow, with the last installation scheduled for 1994 [Fig. 2].

David Nussbaum, ASDE program manager at Norden Systems, told *Spectrum* that the schedule stretched out because the FAA requested additional features, such as more flexibility for controllers to change what is displayed on their screens and smaller keypads. ASDE3 uses some 93 000 lines of PLM code. The challenge, Nussbaum said, was to make the software operate so quickly that the information displayed for the controller is less than 1 second behind the target detected by the radar. Also,

because surface radar is tracking objects that are very close and can move large distances in a short time, ASDE3 turns at 60 revolutions per minute, compared with the 8–16 rpm of typical radar. The speed increases the amount of data that must be processed. At the end of 1990, yet another feature was added to the ASDE specification—automated conflict alert. Conflict alert software is currently being tested.

After the first ASDE3 was installed at Pittsburgh, an unexpected problem put additional ASDE3 installations on hold: when the antenna was heated for de-icing, the skin, which is a fiberglass/aluminum composite, began to blister. Norden has been working with the manufacturer of the material to develop a more heat-resistant composite, and expects to replace the Pittsburgh antenna in April. Norden is also working to fix a software problem—the ASDE resolution is so high that when aircraft are at a certain angle to the antenna, they send back two distinct returns that are reported as separate aircraft.

The schedule for future ASDE deliveries has not been finalized.

In parallel with development of better surface radar, a number of aviation organizations, including the Airline Pilots Association International and the Air Transport Association of America—both in Washington, D.C.—and the FAA are working together to standardize runway markings. A system of lights on taxiways is also being considered; it was tested at Kennedy airport in 1989, but lags in light changes caused delays. In some European airports, lights under the command of controllers are used successfully. The FAA's long-range plans call for taxiway lights controlled automatically with information from radar sensors.

The present interface between the various radars to the air traffic control computers is called PAM (peripheral adapter module), a late 1960s' device. IBM is currently testing its successor, Pamri (PAM replacement item), which will move data at eight times the 2400-bit-per-second rate of PAM, be more reliable, and be easier to maintain. The first Pamri is expected to be installed at the Seattle *en route* center by year-end.

The human element

While new computers, new radios, and new radar can make the air traffic control system safer and more reliable, none of these technologies makes controllers more productive. And that is what is worrying some people.

The FAA has not met its controller staffing goals since the strike. Tony Dresden, director of public affairs for Natca, told *Spectrum* that the Washington *en route* center has seen a 70 per-

cent increase in air traffic since the 1981 controllers' strike and a 30 percent decrease in full-performance-level controllers [see graph, p. 35]. Nationwide, the number of full-performance controllers has fallen from 13 205 in 1981 to 10 000 in 1990; traffic is up from 27.3 million to 38.7 million operations. John F. Thornton, senior director, legislative affairs, for Natca, recently testified before Congress that controllers at busy locations work six-day weeks and 2 hours of overtime per shift (when funding is available) with bare-bones crews.

"There are fewer and fewer controllers working a shift, but there is the appearance that staffing is adequate for the task at hand. It most certainly is not," Thornton told Congress. "Controllers are told they must make do with what is available."

The controller shortage is expected to get worse in 1995; by then half of the full-performance-level controller work force will be eligible to retire. "These controllers will be gone the minute they get the green light," Thornton said. "The money is good for many of them, but it is not worth the aggravation."

Even when tools to enhance productivity are installed, the controllers' association is concerned that transition to new equipment will exacerbate staffing shortages: while some controllers are being trained on the new equipment, others will have to man their posts.

The first new technology expected to increase controller productivity is controller workstations and related software and peripherals: the initial sector suite system (ISSS). These workstations will be used for both *en route* traffic control and approach control by connecting to the new host computers.

Today's controllers track air traffic on round monochrome displays. In addition to basic information about the aircraft (location, speed, altitude, and flight number), the systems warn controllers about imminent conflicts and indicate masses of precipitation. The planned ISSS will be a full-color system that makes conflict alert and weather information more easily distinguishable. Each console will have a 2048-by-2048 resolution 20-by-20-inch (50-by-50-centimeter) main display and a 1024-by-1024 auxiliary display measuring 19 in. (48 cm) on the diagonal. The current system uses one 19-in.-diameter round radar screen and a rack of paper flight strips [Fig. 3]. The new system will be flexible. While today each display is dedicated to control of a certain sector of airspace, ISSS workstations will be reconfigurable at will, allowing a controller at slack times to use several screens and control a larger area of airspace than is possible during busy times.

The ISSS will also have so-called electronic flight strips. While today, information about a flight's origin, destination, and clearance is printed on paper slips that rest next to the control display, ISSS will display flight strip information on an auxiliary monitor. Today, the printed flight strips are the ultimate backup should the radar system go down; they are scheduled to be removed when ISSS is installed, which may cause controllers some discomfort for a while. Natca's Dresden told *Spectrum* that when the ARTS computers went down on that busy autumn day in Dallas, controllers were relying on memory and on flight strips. "That physical backup was helpful," he said.

The high-resolution monitors will be manufactured by Sony Corp., Tokyo; the display controllers will be manufactured by Raytheon Corp., Lexington, Mass. IBM System/6000 workstations with Ada software will provide the computing power.

For the first time in air traffic control equipment development, controllers are having a say in the design of ISSS. Their input is being taken seriously. For example, the initial system specifications called for a function keypad on each side of the Qwerty keyboard; but when controllers said they preferred more room on their desks to being able to access function keys with both hands, one keypad was dropped. Initially color will be used conservatively—red for emergencies, white for data that has recently changed—until controller feedback indicates what information is best called out in color, IBM's Carson said.

Originally planned to be deployed in 1992, ISSS development

is currently delayed by 19 months, according to contractor IBM, but some industry observers find that figure overly optimistic.

Delays in deployment of ISSS—expected to affect the rest of the Advanced Automation System schedule—"have the potential for affecting FAA's ability to handle safely the predicted increases in traffic into the next century," according to a 1990 statement by the GAO.

Several factors are contributing to ISSS delay. According to the GAO, the primary causes are an overly ambitious software development schedule and the FAA's and IBM's inability to resolve key requirements issues. IBM's Carson attributes six of the current 19 months of delay to specification changes made by the FAA and the rest to IBM's underestimation of the complexity of the requirements. The most troublesome concerned the electronic flight strips, which involve complicated cross-referencing of data, and the difficulty of translating those requirements into instructions the company's programmers could follow. (Del Balzo of the FAA attributes three to four months of delay to specification changes.)

Contributing to the delay, Carson told *Spectrum*, was a lack of communication between IBM and the FAA during the design competition phase.

Also, Carson said, IBM had expected Ada development tools to be available commercially, but could not find the necessary software, so the company's programmers had to write their own. (ISSS will use about 1 million lines of Ada code.) A final factor in the delay was the effect of a three-month hiatus caused by a protest by Hughes Aircraft Co., Los Angeles, which had also bid on the project. "We had not properly evaluated the effect of stopping the team and lost momentum on the project," Carson said.

Controllers, however, have one serious concern that will apparently not be addressed soon—the electromagnetic effects of being virtually surrounded by large color monitors.

"The Natca safety committee is not happy with the use of CRTs and low-level electromagnetic radiation," said safety committee chairman Barbour. "We have documented miscarriages and abnormal cancer rates (though no formal study has been conducted). We are concerned with making the old equipment safer, and we are going to try to talk the FAA into replacing the ISSS CRTs with liquid-crystal displays. Controllers can't sit back from the screens to be safe from electromagnetic radiation."

IBM's Carson responds that the company follows all Government specifications for radiation (there are no specifications for extra-low-frequency electromagnetic radiation), and is monitoring the medical literature, but does not plan any design changes at this time. No liquid-crystal displays of the necessary size and resolution are commercially available, so this solution is some time off.

ISSS is only an early step on the way to a highly automated air traffic control system that, it is hoped, will increase both capacity and safety dramatically.

2. Satellites and artificial intelligence promise improved safety and efficiency

On the sixth floor of the U.S. Federal Aviation Administration (FAA) building, opposite the Washington Mall's Smithsonian museums and their hordes of tourists, is a nexus of computers where about a dozen operators peer at some displays measuring 5 feet (1.5 meters) on the diagonal and try to match daily air traffic demands with capacity nationwide, in the process affecting more than a million passengers a day.

It is here at the Central Flow Control facility where, to the frustration of some pilots, airlines must call early each morning to jockey for the fixed flight routes with the "fewest wind miles,"

John A. Adam Senior Associate Editor

based on weather forecasts at various altitudes. The facility is also the source of frequent ire to controllers, who must often deal with Central Flow Control's sending them more than the 20 aircraft tracks that each can now reasonably handle at once.

This will all change within 10 to 15 years, when U.S. air traffic is expected to double. By then airliners will rely more on satellites and on-board capabilities and less on ground control, and controllers still working will use automation to handle up to 50 aircraft simultaneously, authorities like Martin T. Pozesky, chief architect of the FAA's US \$25 billion automation plan, told *IEEE Spectrum*.

By the year 2000, the FAA goals are to sharply reduce staff and to operate at 1980 budget levels despite greatly expanded traffic. Many similar upgrades are expected in Europe and East Asia, where skyways are congesting even faster. But nowhere are modernization plans as ambitious as in the United States, where, for example, artificial intelligence is to extensively help manage traffic.

No one knows what the air traffic control system will be like in 10 or 15 years—the FAA recently adopted a more flexible modernization plan in face of criticism about possible leapfrogging alternatives from satellite technology—but what follows is an examination of some current bottlenecks and technical trends.

Tighter landings

Today 28 airports enplane nearly 70 percent of all U.S. passengers. Twenty-one of these now experience more than 20 000 hours of annual flight delays at a yearly cost to airlines and U.S. businesses of "at least \$5 billion," according to a 1990 report by the U.S. Department of Transportation.

By 1997, despite automation, the FAA forecasts that 33 airports will suffer this level of delay. Busy airports will get busier. The greatest proportion of capacity increase is expected in the big cities, where airports are already overburdened—and where large expanses of real estate for additional runways are often scarce or prohibitively expensive.

Alternative means of transport, such as high-speed trains and tilt-rotor planes, may ease some airport congestion. But as Edith Page, a transportation analyst at the U.S. Congressional Office of Technology Assessment, Washington, D.C., said, passengers insist on faster travel at convenient hours. This, coupled with cheaper fares and smaller passenger planes, stresses the system.

Because most major airports have limited room for expansion, and social pressures often preclude building new airports, boosts in capacity must come from more tightly orchestrated operations, reductions in the distance between aircraft and between runways, and—probably most important—the ability to continue normal operations in bad weather.

From a controller's point of view, nothing is more demanding than rush-hour arrivals, when a converging swarm of planes of varying velocities, sizes, and altitudes must be sorted out without much hesitation and allowed to land on a strip of pavement. Unlike traffic jams on the ground, stopping is not an option. In essence, four dimensions (time and three-axial space) are condensed into one: a stationary point at the terminal gate.

Many tools are being devised to help make this funneling process more efficient. Among them are an integrated set of trajectory and sequencing algorithms and expert systems called CTAS (center/tracon automation system), devised by Heinz Erzberger and his colleagues at the National Aeronautics and Space Administration's (NASA's) Ames Research Center, Moffett Field, Calif. After viewing simulations based on arrival traffic at the Denver Stapleton International Airport, Captain William Cotton, a pilot and air traffic expert at United Air Lines Inc., near Chicago, estimated that, at \$1 per gallon, CTAS could save United about \$44 000 each day in fuel.

The reason is that CTAS, like some other projected systems, computes the best cruise and descent profiles (speeds and altitudes) for a more direct flight from about 200 miles (320 kilometers) to a given airport within a particular time. Computations

consider drag and other characteristics unique to each particular plane model as well as wind velocities at various altitudes. Erzberger said CTAS will eliminate individual controller sequencing "by guess and by gosh," which results in inefficient arrival flows and overly conservative spacing.

According to the Denver simulation, run by controllers from the airport, the landing rate rose from about four to 43.4 aircraft an hour using CTAS. Erzberger said CTAS's most important contribution is reducing controller workload, followed by fuel savings and delay reductions.

Condensing the "safe-following distances" between planes into an airport in terms of the wake vortex problem is being examined at NASA Langley Research Center, Hampton, Va. John Garren, chief of the center's Flight Management Division, estimated that the length of a traffic stream could be halved if the sequencing was optimized for wake vortex consideration and capitalized on other technologies. The present procedure requires spacing of 2.5–6 nautical miles between planes, depending on the types of leading and following aircraft and on runway occupancy times. In the worst conditions, the corkscrew turbulence behind a big aircraft may persist along the flight path for several minutes and wreak havoc, especially with lighter aircraft. More research on this phenomenon is needed to obviate the "worst-case assumptions" that generate conservative spacings between aircraft, said Garren.

Larry Barber, a controller at Washington *En Route* Traffic Control Center, Leesburg, Va., noted that the biggest limiting factor during good weather is runway occupancy time, about 55 seconds between planes. Consequently, new high-speed runway exit ramps are in the works at busy airports like Chicago's O'Hare International. NASA Langley has also examined precision touchdowns—about one aircraft dimension, using advanced flare laws and microwave landing system (MLS) technology—to help planes turn off safely at the correct exit.

Work at Lincoln Laboratory, Lexington, Mass., is also rebutting the view that only more runway space will solve capacity problems. For instance, a simulation using data collected from Boston's Logan International Airport (on a cloudy day with some precipitation) found that airport capacity could be improved by as much as 23 percent if the timing and sequencing of plane arrivals were improved under existing procedures.

The need for greater airport capacity has bred intense interest in new technologies that allow arriving planes to use parallel runways simultaneously, even in poor visibility. Also of interest is bunching runways more closely together, especially in metropolitan airports short of space. Currently, if two parallel landing strips are closer than 4300 feet (1300 meters), arrivals must be restricted during poor visibility. This reduces airport capacity by as much as 25 percent, according to the Lincoln Laboratory.

Raymond R. LaFrey, a researcher at the lab, has used a modified Mode S radar—which allows each transponder-equipped aircraft to be individually and accurately addressed—to monitor approaches at parallel runways in Memphis, Tenn., the hub of Federal Express Corp.'s extensive, and time-critical, operations. If restrictions are relaxed for runway spacings as low as 3400 ft (1040 meters)—which seems feasible with Mode S surveillance when it is combined with an automatic alert warning planes that stray from approach paths—then such parallel runways at Memphis; New York City's Kennedy International; Houston, Texas; Detroit, Mich.; Raleigh-Durham, N.C.; and Los Angeles could operate nearly at usual "clear-weather" capacity during poor visibility, according to LaFrey. Pozesky and others, in a recent FAA concept paper [see To probe further], noted that in the future, even 2500-ft (760-meter) runway spacings "will be routine" and may spur runway construction within airports.

Weather blamed

The FAA blamed weather for 53 percent of the 403 978 delays in fiscal 1990. A simulation by Mitre Corp., McLean, Va., showed how a snowstorm in Denver will cause average delays of

about 30 minutes per plane at 10 airports, from Los Angeles to Chicago, despite ideal weather at them all. With the enhanced runway capacity of the proposed new Denver airport (which will have three sets of independent parallel runways, compared with two sets of dependent runways at Stapleton), most average delays per aircraft at affected airports shrink to about 5 minutes.

To better anticipate weather problems, the FAA is spending more than \$4 billion to build a system whose centerpiece is the next-generation weather radar, known as nexrad. A multi-agency project, the system will be useful for wide weather surveillance, primarily in the *en route* areas. Hampered by delays, it is now scheduled to be fielded at 45 locations, starting in the storm-prone Midwest in 1993. The Doppler radar operates between 2.7 and 3.0 gigahertz with a 1 degree pencil beam; it will produce more than 100 products, mostly graphical, such as winds aloft and wind

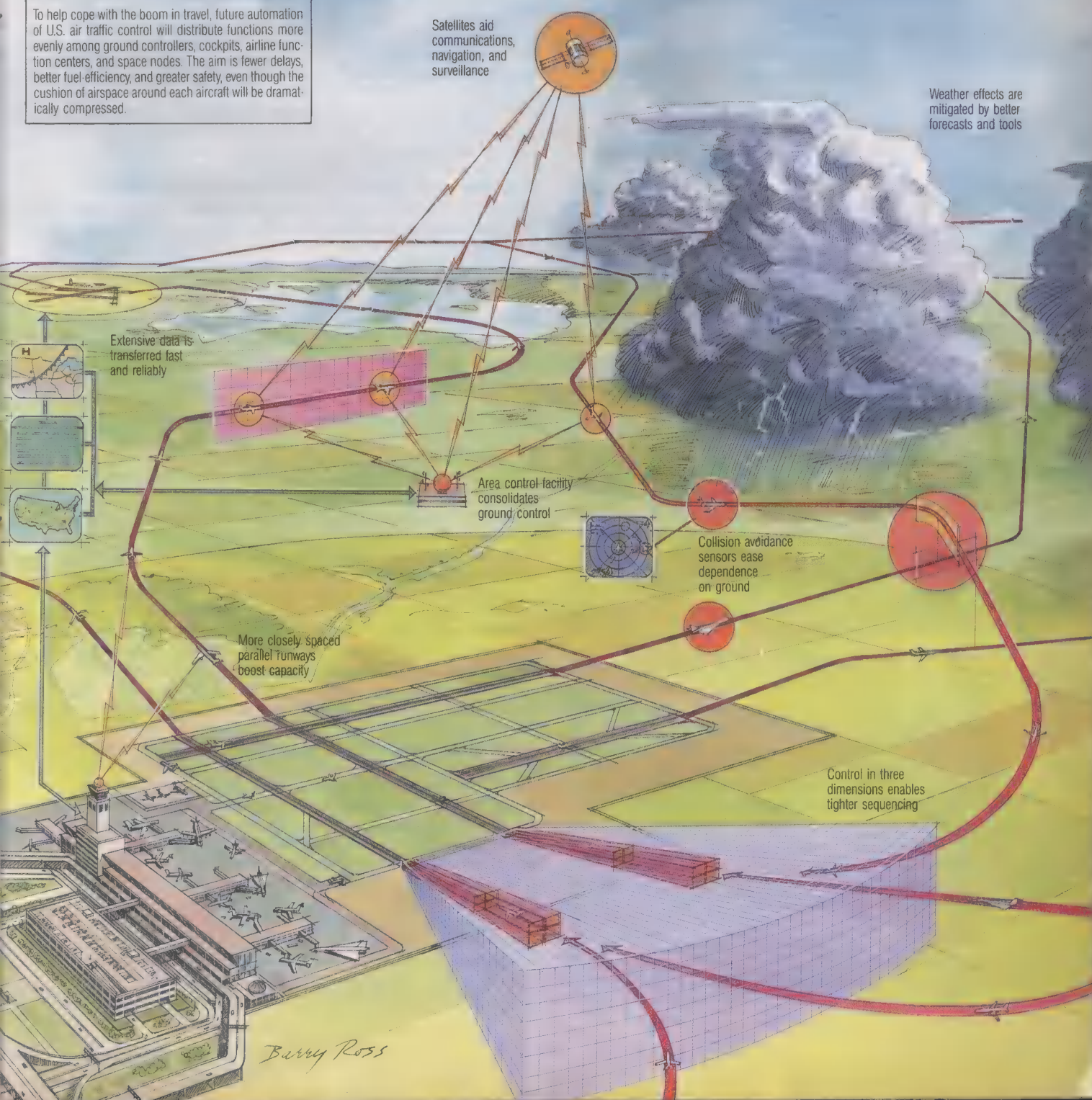
shear velocity data. Starting in 1992, a narrower (0.5 degree) beam Doppler radar is to be fielded at more than 100 sites to detect, in real-time, wind shear and related phenomena in the terminal areas. Expert systems are to be applied to the data to diagnose low-level wind shear.

Within aircraft, the National Transportation Safety Board (NTSB) is stressing continued development of on-board wind shear detection systems. The cockpit may also be modernized with "synthetic vision," allowing pilots to see and land during poor weather conditions (Category 2) without ground systems like the MLSs. The FAA, with the Department of Defense and industry, plans to test a prototype on an executive-class plane in 1992. Perhaps the ultimate is NASA Langley's rear-projection system, which can create a panoramic 3-D display of about 40 by 15 inches (100 by 150 centimeters). Such large displays, depicting a "tun-

To help cope with the boom in travel, future automation of U.S. air traffic control will distribute functions more evenly among ground controllers, cockpits, airline function centers, and space nodes. The aim is fewer delays, better fuel efficiency, and greater safety, even though the cushion of airspace around each aircraft will be dramatically compressed.

Satellites aid communications, navigation, and surveillance

Weather effects are mitigated by better forecasts and tools



nel in the sky" of (say) traffic converging before parallel runways, may enable flight crews to anticipate and detect blunders quicker than conventional concepts, said Garren. It may even be required for landing advanced aircraft such as the High-Speed Civil Transport, which NASA expects to debut in 2005.

For landings in bad weather, including "zero-zero" ("no visibility, no ceiling at any level," ■ Category 3 touchdown), pilots will rely on microwave landing systems if the FAA and the International Civil Aviation Organization (ICAO), Montreal, have their way. Computed glide paths are possible using the minimum performance standards of MLS equipment, which state, for instance, that there must be a 95 percent probability that vertical accuracies are inside a margin of ± 15 ft throughout the coverage and inside ± 2 ft within 2 nmi of the runway. MLS would also be useful in giving precise guidance to those who missed approaches during bad weather and in "fanning" consecutive departures.

Critics do not question the precision of MLS but rather its cost. Each runway would need two MLS units to operate in both directions, at a nationwide cost of \$1.1 billion, according to the FAA. And each cockpit would have to make space for special equipment, something airlines and frugal-minded private pilots are not too enthusiastic about.

A possible alternative is satellite-based guidance, using constellations such as the existing global positioning system (GPS) of the U.S. military and off-the-shelf technology. Initial results from recent flight tests using a special Boeing 737 were "better than anyone expected," according to George Steinmetz, a division chief at NASA Langley. The 737 landed automatically 27 times using exclusively information from the GPS satellite-derived system and a GPS-integrated inertial reference unit designed by Honeywell Inc., Minneapolis, Minn. On average, the plane landed within 2 ft of the runway centerline. Pilots called the automatic landings indistinguishable from those done with the MLS system installed at the test facility at NASA's Wallops Flight Facility in Wallops Island, Va. But data still must be analyzed to see if they fall within the Category 3 tolerances.

The aircraft guided itself (with the supervision of pilots in a windowless cockpit and a backup safety crew that could see) using data from four satellites and a ground station GPS receiver. The station furnished differential corrections to the aircraft by VHF radio.

During the two-month experiment, which ended in December, the GPS was broadcasting unadulterated military accuracies over its civilian channel (possibly because the U.S. military had to snatch up many civilian receivers to meet the demand in the Persian Gulf). But even with the normally downgraded civilian channel, the results would have been similar because of the differential ground station correction, according to Steinmetz.

NASA Langley's Cary R. Spitzer said the system offers the potential for automatic landing capability and other benefits like curved approaches at nearly any airport in the world. In addition, the planes would need only to add GPS equipment, which would be useful in all phases of flight, he noted. A single ground station on a skyscraper in New York City could provide the data for differential calculations for LaGuardia, Kennedy, Newark, and the other airports in the area.

Congress has directed the FAA to speed up transition to satellites and to report on how an earlier introduction might reduce costs. Many users believe extensive satellite operations, including precision landings, can be ready in the 1990s, instead of in 15 to 20 years, as the FAA stated in a November 1990 report [To probe further].

Satellite ranging during the 1990s can improve positional accuracy in the cockpit by an order of magnitude over that provided by radar, according to Delmar M. Fadden, an engineer at Boeing Commercial Airplanes, Seattle, Wash. Radar surveillance may become a backup to the GPS.

Among the limitations of the current worldwide VOR (very high-frequency omnidirectional range) navigation system are the

skyways it creates, which force aircraft to follow from one VOR transmitter to the next. These can get congested at intersections and prevent airliners from flying "as the crow flies" to save fuel. Satellite constellations such as GPS, which form a worldwide grid, will soon change that, allowing all commercial aircraft a position accuracy within 100 meters 95 percent of the time. Ultimately, accuracies of better than 10 meters in three dimensions are possible.

Aircraft narrowly avoided midair crashes five times in U.S. oceanic airspace during 1988, according to the NTSB. The board added that the recent addition of an American Airlines hub in Puerto Rico, coupled with traffic increases across both oceans, is "straining an already overburdened and inefficient" nonradar system. Relief may come from automatic dependent surveillance (ADS), a technique developed by the ICAO, which uses satellite communications to relay position data to ground controllers from an aircraft's on-board navigation system. Besides oceanic tracking, it may prove to be a cost-effective alternative to radar in many remote parts of the world. Currently, airlines must be laterally separated by 60 nmi in the North Atlantic. But the use of ADS and satellite navigation could drastically cut that separation. ADS is being demonstrated now by several carriers. Cotton, who piloted United Air Lines Flight 90 on Dec. 14 from Tokyo to Los Angeles using ADS, called it "beautiful" and potentially more accurate than radar.

Pilots (and passengers) might be reassured on flying into these busier airports to know that the plane has its own collision avoidance sensor. After more than 30 years of development work, the U.S. airline fleet will soon be equipped with traffic alert and collision avoidance systems (TCASs). The sensor system has been operationally tested on Northwest Airlines, Piedmont Aviation, and United Air Lines aircraft, and pilots appear to like it. High false alarm rates, a big area of concern, have not been ■ problem, according to several pilots.

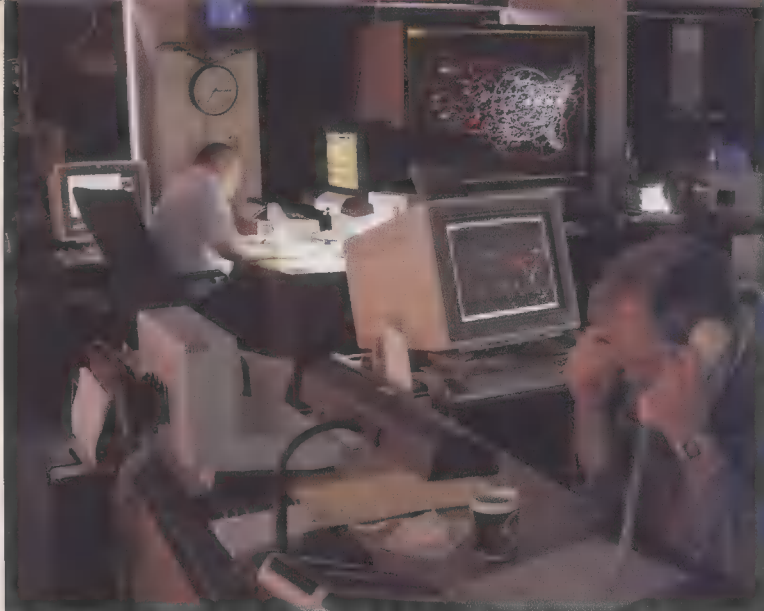
TCAS I, the least expensive option intended for small airplanes, will alert the pilot to an intruding craft. TCAS II, for airliners, will recommend resolutions: either climb or descend. TCAS III will add: turn left or right. In the future, cockpit traffic displays with extensive links to ground and satellites may help flight crews monitor in this crowded environment more thoroughly.

Communicating without garble

With a more coordinated air traffic control role between pilot and ground—and with tighter spacing between planes—reliable communications are critical for timely responses. Even now, communications problems count as ■ big factor in controller productivity and flight safety. The FAA said miscommunication accounts for 23 percent of operational errors.

Because of very high-frequency (VHF) congestion and its party-line nature, "it frequently takes a long time to get a message back and forth," noted United pilot Cotton. Peter Maunsell, a controller at the Seattle tracon who heads the Washington, D.C.-based National Air Traffic Controller Association's technology committee, estimates that up to one-third of a controller's time is spent on communicating, or trying to communicate, by voice.

Because routine messages—such as "switch frequencies," "adjust altitude," or "wilco" (will comply)—are relatively short and simple, and can often be repeated like weather data for various planes, sending discrete written messages should greatly boost efficiency. Nicholas J. Talotta, a program manager at the FAA Technical Center, Atlantic City, N.J., found that if 70 percent of the aircraft were equipped with a data link, voice communications for the controller could be reduced by as much as 45 percent. To the surprise of NASA Langley's Steinmetz, a two-month test last year with eight airline crews showed much faster reaction times using data rather than voice links. Mistakes and repeat messages also were reduced, as pilots, for instance, pushed a single button to enter new clearance altitudes (sent from the ground) directly into the flight computer.



Jim Pickrell for IEEE Spectrum (photos)

The eastern U.S. portion of the Federal Aviation Administration's Central Flow Control facility on Dec. 27, 1990, shows that U.S. airways were not excessively stressed between the holidays—in contrast to a week earlier, when bad weather coincided with heavy pre-Christmas traffic. Artificial intelligence is expected to increase efficiency.

Tests are under way to create a global digital telecommunications network among aircraft, airlines' operations, and air traffic control centers. The Mitre Corp. and other companies and users are developing an open-system telecommunications network to find the shortest path in the dynamic environment. Data links between more capable aircraft computers and the ground should aid in strategically adjusting a plane's arrival time.

The FAA expects the dominant transmission system for air traffic control digital messages to be the Mode S radar-based technology. Built by Westinghouse Electric Corp., Pittsburgh, and Unisys Corp., Blue Bell, Pa., Mode S will be installed in 133 operational locations, beginning in 1993 at a cost of more than \$1.7 billion. It will allow each transponder-equipped aircraft to be individually addressed and precisely tracked. Designed at Lincoln Laboratory during the 1970s and 1980s, Mode S positional reports are precise to 1/256 nmi in range and about 0.02 degree in azimuth. In addition, digital data can be exchanged on such items as local weather advisories, pilot reports, and altitude confirmation. Aircraft, in effect, become *in situ* sensors for, say, wind speed, which should much enhance arrival predictions for the whole transportation system. Mode S identification tags and communication will also be critical in automating surface traffic operations, a current project at Lincoln Laboratory. But some users, like Cotton, are wondering if satellites might be a better alternative to Mode S.

4-D scheduling

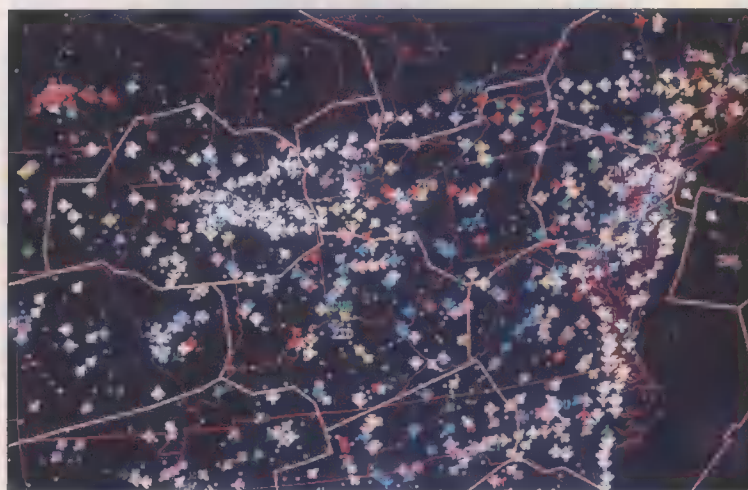
Even though planes equipped with digital flight management systems in the early 1980s ideally could calculate optimal routing, the air traffic control environment still stresses single-file flight along fixed routes and tactical control using radar position data. Newer aircraft such as the Boeing 757 and 767, or the Airbus A310 and A320, schedule flights according to a required time of arrival and fly the most fuel-efficient flight path at the best speed to make that time. With the on-board computers, Boeing's Fadden said that arrival accuracies within 10 to 30 seconds "are readily achievable."

Federal Aviation Administration operators may view traffic flow in varying resolutions—nationwide (above) to a close-up view of the East Coast (below)—as they make decisions that affect more than a million travelers each day, such as whether a take-off should be delayed in Dallas because of congestion in Boston.

In several years, the ground controllers might catch up. The 14 000-odd U.S. controllers handle more than 180 000 aircraft operations each day. A recent FAA report noted many human shortcomings, including limited cognitive abilities when dealing with complex situations, poor vigilance over long periods of monitoring, and vulnerability to error when coping with large amounts of written and spoken data. Plans call for automation to mitigate, if not eliminate, these failings. An FAA goal is to cut operational errors by 80 percent between 1984 and 1995. Joseph M. Del Balzo, the FAA's top technical manager, told *Spectrum*, "The limit to automation will probably be computer training," that is, how well computers can be trained to think like controllers.

Smart machines are appealing. They can have large databases on altitude restrictions for certain planes and on ways those planes respond to climb and descend rates, depending on temperature and pressure. This information can help determine, for instance, if a plane may be expected to cross an intersection at or above 10 000 ft on a hot day, as John A. Scardina of the FAA and two others stated in the November 1989 *IEEE Proceedings*.

The epitome of this automation is probably the automated *en route* air (Aera) traffic control system. In a recent demonstration of Mitre's prototype, the current situation is displayed on a 20-in. (50-cm) screen. Intended flights are projected 20 minutes ahead (and often beyond the sector of a controller today). If the computer spots a conflict, it is highlighted on the screen and a window opens, with recommendations such as "American Flight 66 should descend to 29 000



ft within 2 minutes." As in a game of chess, there are often many moves that are correct in the early stages, and the system will list up to 14 of them (seven per plane), ranked in preference. If, for instance, a pilot would like to conserve fuel at higher altitudes, a controller might check an alternate solution on a second twin monitor, which displays future traffic scenes from 0 to 20 minutes ahead, with the rolling of a track ball. Linked into a nationwide system, Aera is to open up airspace and provide airlines with more flexibility in routing, allowing them to fly more directly and efficiently between cities.

The first version, Aera I, is to alert controllers to potential problems with intended flight routes; Aera II, similar to Mitre's prototype, will rank solutions to the problems. Aera III "will introduce totally automated problem detection and resolution capabilities," according to a recent report by the FAA's Future System Design Working Group, with ground computers communicating directly with those in cockpits.

IBM Corp., Rockville, Md., is to devise Aera I, which uses a classical algorithm, as part of its \$4 billion 12-year Advanced Automation System (AAS) contract. In its first stages, AAS is bringing Unix-based workstation computer technology to controllers. The contract is to be modified by early 1992 to include production of Aera II software, which exists in prototype design at Mitre. The FAA expects Mitre's Aera III to be implemented "soon after the turn of the century." Controllers like Barber have questioned whether they should be liable for Aera's mistakes and whether they should provide reliable manual backup. Robert Simpson, an FAA advisor and head of the flight transportation lab at the Massachusetts Institute of Technology in Cambridge, doubts that flight segments can be reliably predicted when planes descend 2000 or 3000 feet per minute and hit winds varying by tens of kilometers an hour, or when varying temperatures affect climb rates for different engines on different bodies. If assumptions are not based on actual flight data, the results would be "a lot of false alarms and missed alarms," he said.

Akin to Aera but on an earlier schedule are enhancements to the daily central traffic management system allowing the computer to offer resolutions to congestion problems. These are to be operationally validated around 1992. The next stage is to use expert systems to rank the solutions; the last stage calls for automated distribution of the messages and directives.

The final stage begins in the early 1990s and is scheduled to be completed in 2001. Using networks of Apollo computers, new displays, and satellite links, all airliners in U.S. airspace can be depicted with their intended routes as broken lines. From a 3000-nmi national perspective, one can examine various scales and zoom in as close as 20 nmi to examine particular airports. Flights of interest, such as all Denver arrivals, can be highlighted to help traffic planners, who may also call up tags on individual aircraft.

The information, on aircraft situation displays, is shared by control centers via satellite and, since fielding began in the late 1980s, has already resulted in fewer delays nationally as well as in new procedures in Los Angeles, according to Manuel F. Medeiros, chief of automation applications at the Department of Transportation's John A. Volpe National Transportation Systems Center, Cambridge. Nearly 1 million messages (from area centers, terminals, and weather services) are processed daily for updates. Plans call for creating a second central hub site with independent data streams for redundancy.

Criticisms of extensive automation in general, noted by V. David Hopkin of the Royal Air Force Institute of Aviation Medicine, Farnborough, Hants., England, in the November 1989 *IEEE Proceedings*, include impairment of the controller's understanding of the current situation. "Tasks may become dull, boring, unsatisfying, and ultimately unacceptable as the opportunities to develop and exercise skills or to become fully and actively involved in the control of aircraft traffic are curtailed," he said.

Capable machines might mask inadequacies in new controllers, too. If a system fails, manual reversion becomes impossible, since there is far too much for controllers to do themselves. Hopkin

added that most nations are "more circumspect" about automation such as Aera III that may implement solutions without reference to the human controller.

A recent FAA report, "The National Plan for Aviation Human Factors," repeats some of these warnings and advocates "human-centered" automation to exploit the human ability to deal with unforeseen predicaments. In the past, the report says, people often were simply given the tasks that could not be automated.

Redundancy

Pozesky told *Spectrum* that "it's not reasonable to limit the system to human ability," so that manual backup could take over at the same high capacity if automation fails. Rather, he said, "several levels of overlapping coverage" will ensure safety. If Aera fails, for instance, greater capabilities in the cockpit from TCAS and satellites may help the traffic in the air.

If the cushion of airspace around each plane is compressed as much as envisioned, it becomes more critical that degradation of automated functions is gradual. The modernized system must tolerate malfunctions of key parts—from false alarms and software bugs to power failures, cut optical-fiber cables, and fires.

Nearly all pilots and controllers can relate horror stories about lost communications and displays. On Jan. 4, for instance, when AT&T Co. accidentally cut an optical-fiber cable in New Jersey, the New York area's three main airports lost long-range radar for 102 minutes, with the result that hundreds of flights were delayed or canceled.

Overall operational availability of the National Airspace System was 98.52 percent during 1990; equipment failures caused 6623 delays, or 1.6 percent of the total, according to FAA statistics provided to *Spectrum*. Power outages from commercial facilities and backup sources have decreased significantly since 1983. But still, in the first five months of 1990, FAA backup power failed in 161 instances, causing 1171 hours of blackout.

Software reliability may be the stickiest point, especially since a different sort of traffic management system, AT&T's switching network, failed for 9 hours in 1990 because of a faulty software modification.

The centerpiece of the FAA's near-term air traffic control upgrade, IBM's AAS, is to use one Ethernet and four different token-ring networks for greater reliability and reconfigurability within a control center, according to Jonathan D. Dehn, IBM's chief software architect. IBM is drawing on previous experience in high reliability with the space shuttle. Dehn told *Spectrum* that the air traffic control system will not employ as stringent a fault-checking system as the shuttle (which uses different computers to check each other) because of the greater extent of air traffic automation and the "worse consequence of failure" with the shuttle.

Even so, the system is to have more than 2.3 million lines of mostly Ada code and core functionality 99.999997 percent of the time—or no more than 3 seconds of downtime a year, assuming electric power availability. A later addition to the contract by the FAA specified that the system must restart within 30 to 60 seconds once power is resumed.

Because of extensive consolidation of facilities (for instance, approach controls from Raleigh-Durham to Philadelphia may be brought into the Leesburg, Va., center), such things as power outages, fires, and water-main breaks become more critical. Edward Kelly, the FAA's airway facilities manager, called the consolidation the biggest reliability challenge ever faced by the FAA. The FAA, consequently, is revising its earlier estimate to consolidate to only 23 so-called area control facilities.

According to the FAA's Del Balzo, a new National Simulation Center for evaluating new technologies, procedures, and failures in the context of the air traffic control system is to be centered at the FAA Technical Center, but it will be networked with laboratories and flight simulators nationwide. United Air Line's Cotton noted that such a capability will be "good if it's used right, but watch out if it's misused." ♦

3. Expert observers define top priorities to ensure safe and accessible skies

Impending crises in U.S. air transportation are not new. The introduction of fast-flying commercial jets, high-profile collisions like the one between United and TWA airliners over the Grand Canyon in 1956, and more recently the cheaper fares and resulting swarms of air traffic from deregulation have all spurred reviews and changes in aviation, safety, and management over the last several decades.

With this in mind, Spectrum asked various experts to respond to two questions: what is the No. 1 problem with the U.S. air transportation system today, and what would be your ideal plan to make improvements for a safe, efficient system in the year 2000?

The experts who participated are:

Robert J. Aaronson, president, Air Transport Association of America (ATAA), Washington, D.C.

Captain Randolph Babbitt, president, Air Line Pilots Association (ALPA) International, Washington, D.C.

James Banks, vice president for operations, Air Traffic Control Association (ATCA) Inc., Washington, D.C.

Stephen R. Bassett, senior vice president, Aircraft Owners and Pilots Association (AOPA), Frederick, Md.

Jim Burnett, member and former chairman, U.S. National Transportation Safety Board (NTSB), Washington, D.C.

John J. Fearnside, senior vice president, general manager, and director, Center for Advanced Aviation System Development, Mitre Corp., McLean, Va.

John B. Galipault, president, Aviation Safety Institute (ASI), Worthington, Ohio.

Captain David R. Haapala, director of future flight programs, Northwest Airlines Inc., St. Paul, Minn.

Glenn Johnmeyer, captain and simulator instructor, Boeing 747, United Parcel Service, Louisville, Ky.

Hart Langer, senior vice president, flight operations, United Air Lines Inc., Chicago, Ill.

Senator Frank Lautenberg (D-N.J.), chairman, transportation subcommittee of the Senate Appropriations Committee.

Representative Norman Y. Mineta (D-Calif.), former chairman of the aviation subcommittee of the Committee on Public Works and Transportation, 1981-88; presently chair of the surface transportation subcommittee.

John J. Nance, Tacoma, Wash., author of Blind Trust, a 1986 book on airline deregulation's effects on safety, and Splash of Colors, the 1984 story that focuses on the Braniff Inc. airline's decline and bankruptcy.

Representative James L. Oberstar (D-Minn.), chairman of the aviation subcommittee of the Committee on Public Works and Transportation.

Nawal K. Taneja, professor, department of aviation, Ohio State University, Columbus; a former president of a commuter airline and an analyst for TWA; and author of nine books on U.S. and international aviation.

(James Busey, the Federal Aviation Administration's head administrator, decided not to participate.)

Tekla S. Perry Senior Editor

John A. Adam Senior Associate Editor

Overwhelmingly cited as the top problem was throughput capacity—or rather growing lack of capacity. The reasons given for this deficiency, however, varied widely.

"We are quickly running out of runway capacity," said Captain Randolph Babbitt, president of the Air Line Pilots Association (ALPA). "Some airports are saturated to the point where the FAA must ration landing slots. Radio frequencies likewise are becoming saturated, and the incidence of missed communications is on the verge of becoming an outright hazard rather than an annoyance."

The risk of midair collisions is still a concern, he said, but it is now joined by the runway incursion problem, "exacerbated by inadequate signs and lighting at many airports."

Nawal K. Taneja, who recently examined this issue as part of a National Research Council study, blamed inadequate airport and air traffic control (ATC) capacity for, among other things:

- Limiting growth of the U.S. air transportation industry.
- Canceling some positive influences from other stimulants (for instance, no freedom of entry at certain airports mitigates price competition).
- Affecting the competitive structure of the airline industry in the marketplace.
- Restricting the airlines' abilities to capitalize on emerging opportunities.
- Costing airlines and passengers and the general aviation industry billions of additional dollars.
- Increasing the public's concern about safety.

James Banks, of the Air Traffic Control Association (ATCA),

told *Spectrum*: "The problem is not necessarily a lack of capacity so much as poor utilization of existing capacity. There is uncontrolled competition among the major air carriers to operate on 'prime time' schedules. As a regulatory agency, the FAA [Federal Aviation Administration] seems powerless or reluctant" to do anything about it.

"The FAA-administered air traffic control system is like a poorly patched boiler pressurized beyond safe capacity, straining to hold together as its owners blindly continue stoking the fire below," John Nance, a writer on aviation, told *Spectrum*. "The key problem? The

object inability of the FAA in particular to select, buy, install, and use current technology—and that failure may in turn be laid at the feet of Congress. We're using the latest technology from 1945: simplex voice, and with marginal maintenance capability to boot. In the inadequately equipped ATC of today, when we try to make people into machines, we gamble with airborne lives."

ALPA's president Babbitt also cited the FAA's outdated resources. "In an era when desktop PCs are common office fixtures, controllers at many facilities are still forced to rely on equipment and software that are decades behind the state of the art."

Crowded airspace, too

Lack of capacity exists not only near runways. "Airspace, at the altitudes where airplanes will fly for the next couple of decades, is finite and crowded in several domestic and oceanic routes," noted Captain David R. Haapala, Northwest Airlines Inc.

Ensuring adequate airport and airspace capacity with no reduction in safety margins is the top challenge, according to John J. Fearnside, an architect of ATC automation at Mitre Corp.

Congressman James L. Oberstar (D-Minn.) called the top problem "the continued financial viability of U.S. airlines, and their continued ability to provide adequate domestic competition, and



to compete with foreign airlines in the international routes." The subject, he added, will be a major focus of the aviation subcommittee he chairs.

The phenomenal air traffic growth of the last decade has prompted a growth of reliever airports, observed Captain Glenn Johnmeyer of United Parcel Service. Rather than building new mega-airports, most metropolitan areas have two or more airports operating at or near saturation. Los Angeles has five. This congestion, he said, complicates matters for both controllers and pilots since the traffic is not all flowing to or from one point.

In the opinion of Stephen R. Bassett of the Aircraft Owners and Pilots Association (AOPA), the biggest challenge is building an ATC system to accommodate all users. "Forgotten in the dialogue is general aviation—that segment which flies more miles and more hours than the scheduled carriers, serves more communities than the airlines, and transports between cities one quarter of the nation's air passengers." He noted services to small and rural communities are eroding, with 73 public-use airports closing in 1989.

The top problem cited by Jim Burnett, former U.S. National Transportation Safety Board (NTSB) chairman, was the "inadequate level of proficiency training and seasoning of captains and first officers in commercial aviation." He added that several recent accidents have demonstrated this lack, "but no one seems to have a plan to deal with it."

Senator Frank Lautenberg (D-N.J.) said the top priority should be safely managing today's congestion while planning tomorrow's growth. Even though the United States recognized the need for a major overhaul of the system in the early 1980s, "solutions were not readily available," Lautenberg said. The FAA could not buy off-the-shelf remedies for such problems as air congestion, weather forecasting, and data transmission. Still the Senator believes, "our failure has been in not making faster progress."

A concrete solution

Can these problems be fixed in the next decade?

"It is too late for an ideal plan for the year 2000," Burnett told *Spectrum*. "In the short run, efficiency and safety will inevitably be in conflict."

There are, however, several critical steps that *Spectrum's* group of experts stressed could be taken to mitigate the problems. One measure that could have major impact, several agreed, seems simple: pour more concrete—that is, build more runways and more airports.

California Congressman Norman Y. Mineta said, "A chief problem in American aviation today is the inadequate capacity," which exacerbates the congestion.

"Construction of new airports and additional runways must be speeded up considerably, and may require a jump start from the FAA or the Congress," ALPA's Babbitt said.

But a wave of new airport construction is not expected anytime soon. "This is the most expensive solution," pilot Johnmeyer told *Spectrum*, "and therefore the last one you are likely to see." Denver, Colo., is the only major city building a new airport, Johnmeyer said, and ironically Denver's existing airport, Stapleton International, is probably one of the few major airports in the United States that has room for on-site expansion. "The money could be better spent elsewhere," he said.

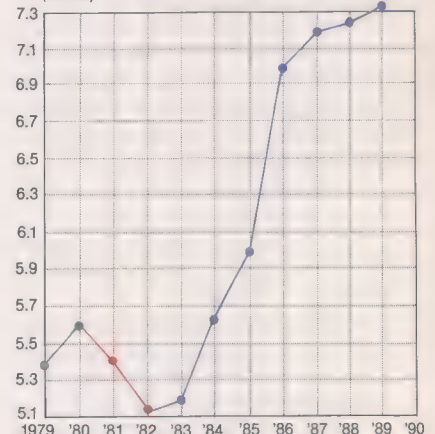
In the meantime, several experts indicated that demand for aviation facilities must be restricted. "Congestion at airports, especially the hubs, will require efforts by the airlines to reduce and better coordinate their flight schedules," ALPA's Babbitt said. Demand management, however, could affect the cost and convenience of air transportation.

According to Ohio State's Taneja, "The long-term solution to the inadequate capacity of the U.S. airport and air traffic control system is a combination of capacity enhancement and demand management techniques. The implementation of demand management techniques will be facilitated by allowing airports to utilize differential pricing policies, collect passenger facility

The U.S. air transportation

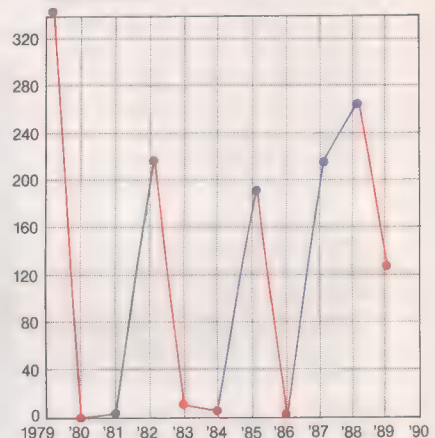
1. Total annual departures of scheduled airline services, in millions

Source: National Transportation Safety Board (NTSB)



5. Fatalities of passengers aboard scheduled airlines

Source: NTSB



Key: Blue lines indicate uptrends; red, downtrends. In No. 2, the dotted line indicates gap in reported data due to the air traffic controllers' strike. Subsequent data reflect fiscal, not calendar, years.

charges, and auction slots through a market-oriented mechanism."

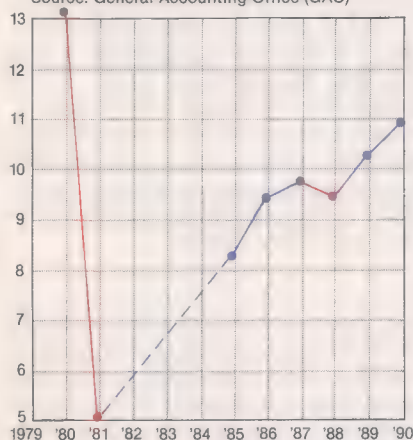
ATCA's Banks urged that the air transportation system "be designed using formulae that match system capacity with user scheduling strategies to avoid degradation of safety. The Government should let it be known that flight activities using the system must operate within the limits of that system. Should such warnings be ignored and more activities (or flights) scheduled that will exceed the designed capabilities of the system, users should accept the resultant self-induced delay and consequent penalty. This is 'hard ball' regulatory action. It's overdue."

"Admittedly," Banks continued, "to force this issue would create havoc, which in turn would attest to how the current system is abused and to the implications of deteriorating safety due to pressures and stresses generated by an overworked system."

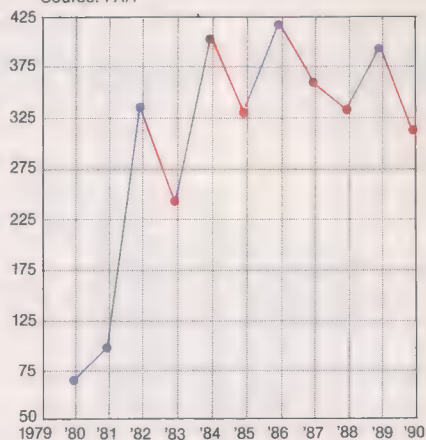
NTSB's Burnett agrees that "a system that allows an adequate safety margin for the air traffic control operations both on the ground and in the air will to some degree restrict the expansion of the aviation industry."

Hart Langer of United Air Lines advocated more "attention to overcoming the unnecessary bottlenecks in the nation's airspace," like installing new computers for tower and tracon

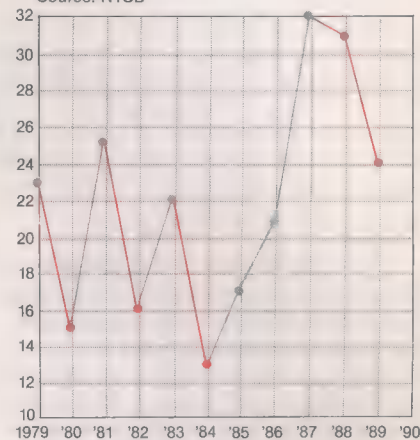
2. Full-performance-level controllers in the Federal Aviation Administration (FAA) workforce, in thousands
Source: General Accounting Office (GAO)



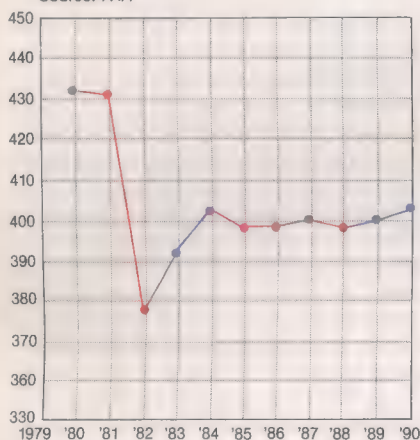
3. Flights delayed by more than 15 minutes due to air traffic system problems, in thousands
Source: FAA



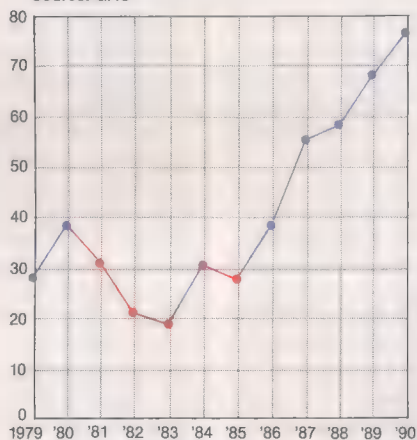
4. Accidents involving scheduled airline service
Source: NTSB



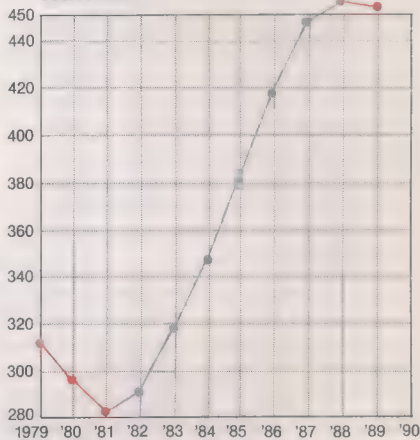
6. Airports with FAA-operated towers
Source: FAA



7. Uncommitted balance of airport and airway trust fund, in millions of U.S. dollars
Source: GAO



8. Passengers on scheduled and nonscheduled commercial flights, in millions
Source: FAA



Note: In 1978, the Airline Deregulation Act was passed; by 1980, most deregulation of routing and pricing was completed. In 1981, the Professional Air Traffic Controllers Organization went on strike, and all striking controllers were fired.

controllers, real-time flow displays for airlines to help them fine-tune schedules, and landing systems to allow converging approach paths. "The FAA must speed up the process of replacing outdated hardware and software at its ATC facilities," ALPA's Babbitt also urged.

Perhaps the most important new technology will be installed in the sky, not on the ground, indicated Bassett of the AOPA.

Northwest Airlines' Haapala agrees. "There will be a transition from a terrestrial-based communication and navigation system to one that is satellite-based. This will initially use the coming-on-line U.S. global positioning system (GPS), the Soviet Glonass system for navigation, and the Inmarsat satellite communications system." Said John B. Galipault of the Aviation Safety Institute: "I am betting that by 2000 we will have full coverage by GPS. I am also assuming that we will have the critical up-down satellite data links for message/data movement."

In addition to satellite navigation, Galipault expects improvement in takeoff and landing systems, as well as in the ability to operate safely in bad weather. "We see the vast majority of the accidents within the '8 and 3' segments of the flight," he said. "Eight minutes back from the time the aircraft turns off from the runway after landing and the three minutes after brake release for takeoff. This is where we hurt people."

Northwest's Haapala agreed that in the next decade, systems to make takeoffs and landings safer will be developed. He predicted that new navigational capability from on-board flight management computers updated via satellite systems will allow complex, curved, and segmented approaches rather than simple, straight-in procedures, with on-board collision avoidance systems and better radars providing "backup blunder protection."

In the cockpit, Haapala expects to see systems that will predict wind shear and allow pilots to avoid such hazards. Also in use will be enhanced vision systems that will see through darkness and fog, and head-up holographic displays showing flight paths, energy management, and angle of attack. "Combined, these devices should greatly enhance the safety of airliners in the next century," he said.

Pilot Johnmeyer agreed that collision avoidance systems will help pilots see and avoid other air traffic, but he is concerned that these systems were not designed to use head-up displays.

"The flight engineer's position has been the victim of both high tech and the CEO's fixation on the bottom line," Johnmeyer said. "All the new aircraft are being certified without a requirement for a flight engineer. That means one fewer pair of eyes in the cockpit. We desperately need our critical information displayed in such a fashion that we can keep the eyes that we have left

looking outside for other aircraft. With all the high-tech gadgets in the world, the best TCAS (traffic alert and collision avoidance system) any aircraft can have is a well-trained, alert, and experienced pilot. That pilot still needs all the help he or she can get. I feel that a TCAS incorporated into a head-up display would be the best possible safety enhancement for the crowded skies of today and tomorrow."

Until new technology is installed, hiring more controllers is important, Babbitt said. Also, while development of data link transmission of information is an ultimate solution, it will be a decade before it is fully implemented. In the meantime, Babbitt said, it is important "to develop uniform, mandatory communications standards, such as requiring read-backs for all critical radio transmissions."

Restructure the FAA

ATCA's Banks said airline deregulation has prompted many dramatic changes, except in the regulating bureaucracies where it is desperately needed: the Congress, the Department of Transportation, and the FAA.

"Each of the management elements—human resources, procurement, and financing—has suffered from Government shortcomings," said Robert J. Aaronson, president of the Air Transport Association of America.

"Restructuring the air traffic control system is essential to the continued growth of our air transportation system," said ATAA's Aaronson. "The ATC reorganization should streamline administrative, management, and procurement procedures and enable the system to operate in a more business-like manner. A thorough reorganization of the existing ATC system is the key ingredient missing from current plans by the Federal government to improve and expand the ATC system and to make it the efficient component needed... in the year 2000."

"We possess the necessary technical expertise to solve the congestion problem, and all parties—public and private both—have a vested interest in solving the problem," Lautenberg told *Spectrum*. "What we have to ensure is that the FAA has the necessary resources, in both personnel and funds, to do the job. One of the reasons that approximately \$1 billion in funds provided by Congress still exists in the FAA's coffers is the previously fragmented, and sometimes political, approach used to develop and then integrate individual projects." He called for improved FAA management by making it flexible, with clear lines of authority and integrated air and ground operations.

Nance, author of *Blind Trust*, would like to see more drastic changes in the FAA. "The aerospace system of the United States is growing like Topsy with insufficient control, little or no direction, and foresight measured largely in months, not years," he said. "What is needed is nothing short of a total overhaul in structure, philosophy, funding, political clout, decisional independence, and degree of industry involvement. We need to begin with a cabinet-level directorate over air and space."

The buck stops here

The biggest obstacle to improving the air transportation system, *Spectrum's* experts agree, is money—specifically, the reluctance to spend it.

Stated pilot Johnmeyer: "One essential ingredient necessary to correct the weaknesses in our air traffic control network is to spend the \$8 billion surplus in the Federal Aviation Trust Fund for capital improvements."

But, said ALPA's Babbitt, "our nation's aviation trust fund continues to accumulate unspent surpluses while the air transportation system's infrastructure staggers under an ever-increasing burden. The reluctance of the Congress and the Administration to spend increasing amounts on aviation during the current budget difficulties is well understood by all parties; but the impending loss of efficiency and safety will come at a cost that far exceeds any short-term savings to the budget."

There is hope, however. Representative Oberstar told *Spectrum*

that his ideal plan for bringing the U.S. aviation system into the 21st century was set in motion with the Aviation Safety and Capacity Expansion Act of 1990, just passed. "First," Oberstar said, "the bill increased funding for airports and the national airspace program, and will spend down the \$7.6 billion surplus in the Aviation Trust Fund to \$1.1 billion by 1995. These extra dollars will permit the airports to increase their capacity to handle traffic and will allow the FAA to continue to improve air traffic management in the skies." The same bill included provisions to phase out noisy planes in favor of quieter aircraft.

"I look forward with confidence to the year 2000," Oberstar told *Spectrum*, "when airports will be able to handle more traffic safely, the FAA will be able to manage the same traffic more safely in the skies, and a national noise policy will have largely reconciled this issue, thereby permitting airports to expand without massive resistance by local citizen groups."

To probe further

The Capital Investment Plan, which lays out all the air traffic control projects under development, is published by the Federal Aviation Administration (FAA) and updated regularly. To order the plan, contact: Associate Administrator for NAS Development, the FAA, Room 500 W, 800 Independence Ave., S.W., Washington, D.C. 20591; 202-267-3065.

Other recommended FAA publications include "Report of the Future System Design Working Group," November 1990, and "Strategic Plan," August 1990. The first publication is available through the Research and Development Service (ARD-20) at the FAA, 800 Independence Ave., S.W., Washington, D.C. 20591. For the second, contact the FAA's Office of Aviation Policy and Plans (APO-100).

Two interesting reports have been printed by FAA advisory committees: "The FAA National Simulation Laboratory" (June 26, 1990) and "A National Plan for Aviation Human Factors" (December 1990). The first report is available from FAA Publications at the above address. The second is available from the Chief Scientific and Technical Advisor on Human Factors, also at the FAA address above.

In November 1986, *IEEE Spectrum* devoted a special issue, "Our Burdened Skies," to the problems of the U.S. air transportation system. The editorial material from this issue is available as a *Spectrum* compendium, #THO 168-5, at US \$7.50 for IEEE members, \$15 for nonmembers. To order, contact the IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331.

For information about planned air traffic control system changes in Europe, see "Transportation," *Spectrum*, January 1991, pp. 69-71.

As for the future of air traffic control operations, the entire *Proceedings of the IEEE*, November 1989, Vol. 77, No. 11—17 papers—is devoted to the subject. The *Lincoln Laboratory Journal*, fall 1989, devotes 14 articles to its air traffic control research. Contact the lab's publications department: 617-863-2238.

The Radio Technical Commission for Aeronautics (1425 K St., N.W., Suite 500, Washington, D.C. 20005; 202-682-0266), a forum of users and designers, publishes many documents. The proceedings of the Annual Assembly and Technical Symposium it held last December are available for \$29, prepaid.

In November, the National Research Council published Special Report 226, "Air System Capacity: Strategic Choices." Contact the Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418; 202-334-3213. Cost is \$17.

The Congressional Office of Technology Assessment's "Safe Skies for Tomorrow," printed in July 1988, and its shorter traffic alert and collision avoidance system (TCAS) evaluation, "Safer Skies with TCAS," which came out in February 1989, merit study. For a free summary of the longer report, call 202-224-8996. For the full report (PB 89-114-318/AS), contact the National Institute of Standards and Technology, 703-487-4650. The TCAS evaluation (Stock No. 052-003-01149-2) is available for \$2.50 at the Government Printing Office, 202-723-3238. ♦

How to select tools for microcontroller software

Symbolic versus source-level debugging, programming language tradeoffs, and assembler features are factors to be considered along with start-up costs

Choosing the tools for developing software for a microcontroller is no less critical a decision than selecting the microcontroller itself. It may be even more critical, since software accounts for 50-75 percent of the cost of a microcontroller project. Choosing effective and efficient tools helps to keep software costs within bounds and thus reduces the overall cost of control-computer chips embedded in products.

A microcontroller differs from a microprocessor in both type and level of on-chip integration. Containing a central processing unit, memory, and peripheral devices, it typically has on chip all the features needed for a complete embedded application, whether a toy or game or a scientific instrument. Developing the software for any of these applications is an intricate process involving many interrelated variables. The tools used consist of programs that guide engineers in writing the code for the microcontroller application, help debug it, and verify that it works as intended in the microcontroller.

The choice of tools depends on many factors: the type of microcontroller, the programming language, the budget, the time available, the level of reliability expected, the programmer's skill, and the degree of support offered by the tool's supplier, for example. The first step is to determine which microcontroller types can do the job in terms of central processor throughput, input/output (I/O) lines, random-access memory (RAM), read-only memory (ROM), timers, analog-to-digital conversion, and so forth. Then the software development tools available for each microcontroller can be examined to winnow out the microcontroller type that yields the best overall solution.

What programming language?

Most tools are language specific; one for Fortran, say, cannot be used for assembly language, C, Pascal, Fortran, Ada, or Forth. The choice of programming language has far-reaching consequences, for it not only influences the number and types of development tools available, but also determines the software development schedule and future maintenance costs.

Assembly language is generally best for smaller, less complicated applications—appliances like microwave ovens, consumer electronics such as video camcorders, and simple instruments like battery testers. Assembly language is above all exact—and therefore too detailed for the average programmer. Its advantages are that it requires less memory than high-level languages, executes faster, and controls critical peripheral resources more precisely.

Assemblers—development tools for assembly language—range from simple, ROM-based debugging monitor programs to more powerful source-level debugging programs and in-circuit emulation systems with bus analyzers. A simple, inexpensive assembler can only translate source statements from a single file into machine object code. An assembler like this may even be provided



free of charge by the microcontroller manufacturer.

More advanced assemblers offer, in order of increasing complexity and cost, cross-referenced symbol tables, file inclusion, conditional assembly, macros, and structured assembly statements. A cross-referenced symbol table relates each symbol to the line number where it is defined and to each line number where it is used, so that it is easy for the programmer to check all the occurrences of a particular symbol.

File inclusion means the assembler can alter the input stream temporarily to include the contents of another file. And that signifies less work for the developer because of the ease with which common definitions, such as EQU (equates), can now be grouped in a single file for insertion wherever it is needed.

Conditional assembly adds the ability to assemble different portions of code in accordance with the operand field expression, for example, "if equal," "if not equal," or "if greater or equal." The consequence is that one software module can handle several different versions of hardware. Maintenance costs are therefore lower, since only one file needs to be maintained.

Macros are code sequences that the assembler can repeat on demand to create in-line subroutines, including arguments. The user defines a source code sequence as a macro, assigns it a name, and places the macro name in an opcode field whenever appropriate. When the assembler encounters the name, it replays the stored source code sequence and inserts parameters as specified. Macros speed up code execution by avoiding the overhead of subroutine calls while retaining the modular "debuggability" of subroutines.

Structured assembly statements smooth the implementation in assembly language of high-level language statements such as

Defining terms

Bus analyzer: a tool that captures the bus signals at a given instant for later analysis.

Disassembly: translation of binary machine code into assembly language statements.

Module offset: displacement of the beginning address of a software module relative to a module item such as an instruction or data variable.

Operand field: assembly language field operated on by an instruction; contains address or data values, or both.

Program counter: microcontroller register containing the address of the next instruction to be executed.

Source-level debugger: tool whose interface is based on source code files rather than the binary object produced by the files.

Symbolic-level debugger: tool that substitutes symbols for values and whose user interface is based on the binary object produced by source code files.

Peter S. Gilmour Motorola Inc.

IF-THEN-ELSE, FOR, DO, and WHILE loops. Like macros, they make programmers more productive by generating error-free code sequences on their behalf.

High-level languages

High-level languages are favored in larger, more complex applications such as automotive electronics, instrumentation, and industrial automation. They relieve programmers of the chore of attending to the low-level details of assembly language and thus make programming faster, easier, and more accurate. Drawbacks to high-level languages are their higher memory requirements and slower execution, but these are often negligible today, with the high bus speeds and power available in even moderately priced microcontrollers.

C has emerged in recent years as the language of choice in embedded control. Its popularity is well deserved, for C combines the best of assembly language (compactness and speed) and high-level languages (portability, control flow constructs, data structures, and modular programming support). Sometimes it is even described as a high-level assembly language.

Development tools for high-level languages range from simple tools for inserting PRINT statements to more powerful source-level debugging programs and in-circuit emulation systems with bus analyzers.

Whatever the application, the entire cost of the development tools must be considered, including the host computer system (the platform), the development system (high-level-language compiler, assembler, linker, debugger monitor software, debugger hardware, and cables), and training (whether through formal classes or through reading manuals and learning the systems). Among the more popular platforms for microcontroller development are the IBM PC and its clones, the Apple Macintosh family, workstations such as the Sun and HP Apollo systems, and on occasion mainframe computers, such as Digital Equipment Corp.'s VAX. Their costs range from US \$1000 or \$2000 for PC clones to tens or hundreds of thousands of dollars or more for workstations or minicomputers.

Development tools run from a few hundred dollars for an evaluation module-type system with a free assembler, to thousands of dollars for an in-circuit emulation system with bus analyzer, high-level language compiler, assembler, linker, and source-level debugger.

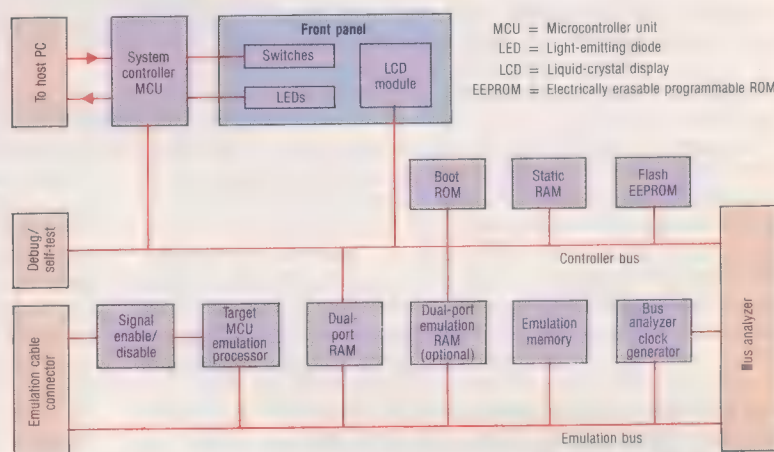
In-circuit emulation involves physically removing the microcontroller chip from the application, or target, system and replacing it with the emulator's target cable [Fig. 1]. The emulator system then replicates the signal actions of the absentee chip in the target system through the target cable. It executes instructions besides generating control signals. Real-time emulation means the faithful reproduction of all target signals in the same mutual relationships as those the real microprocessor would generate. Emulators that require a special socket, connector, or circuit-board layout for the target cable connection should be approached with caution because they may interfere with the application's design. It is wise also to ensure that emulation memory can perform zero-wait-state operation, or real-time emulation may not be achievable.

It is wise, too, to look for a development system with reusable parts that need not be replaced if a different microprocessor is chosen for the next project. For example, can the host computer be reused? What about the development hardware or software? Can the assembler and linker handle more than one microprocessor? Is the user interface similar so that training costs are minimal?

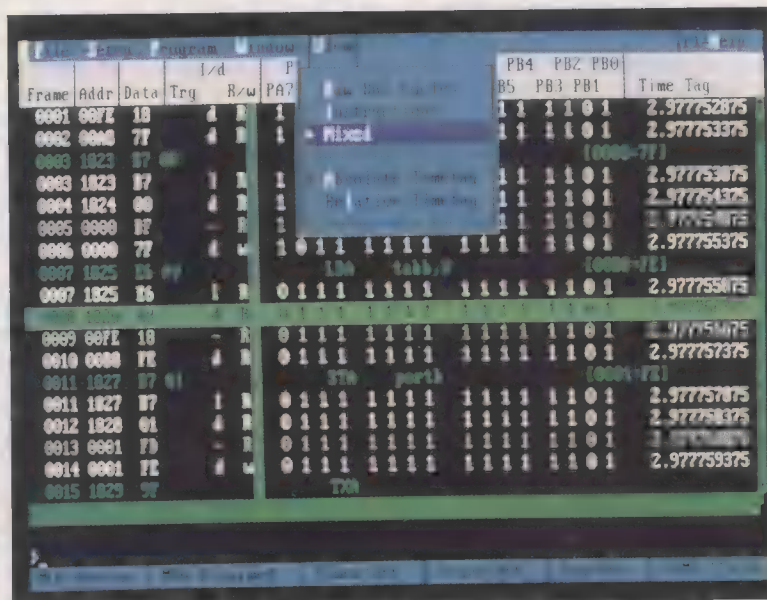
Features that save labor and enhance accuracy are much to be desired. For example, if the debugger does not support a relocatable module system, the operator must often manually calculate module offsets and current program-counter values in the course of debugging the system. Adding a hexadecimal calculator takes the sting out of these calculations, but they are still not nearly as easy as with a debugger that can automatically translate absolute program-counter values into the relative ones shown on the assembly listings in a relocatable module system.

Hidden flaws in software development tools can wreak havoc with a development schedule. The most common—and insidious—flaw in a tool is undocumented errors that the user interprets as malfunctions in the application system. Prime examples are a compiler that incorrectly compiles an instruction and a linker that incorrectly links a group of modules. These types of problems can be avoided by consulting magazine reviews, by selecting a vendor willing to demonstrate a system or lend one, or by leasing the system before buying it.

Another kind of flaw in a tool conflicts with the application's operation. This flaw is evident in "invasive" tools that usurp a



[1] An in-circuit emulation board contains the elements for replicating exactly the actions of a microcontroller. During software development and debugging, it replaces the microcontroller in the control system.



[2] Bus analyzer display shows captured bus data. The user has selected the "view" window and has chosen to display a mixture of raw bus cycles and instructions with relative time tags. The display was produced by Motorola's CD58 Jewelbox emulator system.

resource of the microcontroller, such as an interrupt, timer, or on-chip RAM. If, for example, a debugger uses the software interrupt instruction (SWI) to implement software breakpoints, the application software cannot also use them, or at best can use them but with a greatly altered response time.

Noninvasive is better

An invasive tool affects an operation simply by being present—that is, a microcontroller behaves one way when the tool is used and another way when it is not. The differences can be as small as timing variations or as large as usurpation of such microcontroller resources as interrupt lines, ports, timer, and analog-to-digital conversion. Invasive tools are usually cheaper: simple ROM debug monitors, evaluation boards, and simple in-circuit emulators are examples. They are beloved by highly budget-conscious groups—colleges and universities, students, small companies, and experimenters—but large companies sometimes also use them for preliminary design evaluation and prototyping. For final production designs, however, large companies usually buy the best noninvasive tools available to ensure a quality product in the least amount of time.

Noninvasive tools are carefully constructed to replicate all microcontroller functions, including timing, without any differences. The more complex the application, the greater the need for noninvasive tools if the development job is to be completed in a reasonable amount of time. Thus an in-circuit emulator with bus analyzer [Fig. 2] may be required to solve such problems as “Why is my variable being overwritten at random times?” and “Why does the program crash when event A occurs followed by events B and C?” A bus analyzer monitors address, data, and control lines and can trigger collection of these signals at any state the user specifies. The more powerful, and thus more expensive, bus analyzers have multiple triggering capability and very deep trace buffers that can capture 8000 or more cycles of bus activity for later examination by the programmer.

Source or symbol?

In an ideal world, source-level debugging would always be preferable to symbolic-level debugging. But a source-level debugger may not exist for the microcontroller, language, and platform chosen. And even if one is available, it may lie outside the developer's budget. Unless the developer can amortize its cost over more than one project or justify its purchase by the debugging time saved, a less powerful, symbolic-level debugger is in order.

Symbolic debugging uses the symbolic labels generated by the program rather than the absolute hexadecimal values of the labels. Primitive symbolic debuggers force the user to manually enter the symbols and values, while more advanced versions automatically read files for the symbols and values so that there is little chance of error. A file may be an assembly listing file itself, a special symbol table file generated from the assembler or from the linker, or the product of a postprocessing utility program. During the debug process, the user can freely use the symbolic labels to set breakpoints, examine memory locations, assemble program patches—anywhere a value goes, a symbolic label may go also. Program disassembly will match addresses and operands to the symbol table and show them in the assembly-language disassembly display in the proper places.

The program disassembly listing therefore looks like the generated source code listing, but with some important differences. No comments appear in disassembly listings, for example. In addition, in some symbolic debuggers, when symbols have identical values, only the first one encountered in the symbol table will be displayed; if NULL, NONE, and ZERO, for example, all have a value of zero, only one will appear in the disassembly display. And in some symbolic debuggers, symbols whose values accidentally match instruction locations or operands will show up in the disassembly display, confounding the debug process.

Source-level debuggers tightly couple the usually high-level im-

plementation language with the debugging process. They allow the programmer to debug an application program while viewing the source code it was written in. Generally, source-level debuggers let the user step through one language statement at a time, examine and change variable and structure contents by name, and set breakpoints on any executable statement line by marking the line on the screen or entering the line number. The user sees all the comments in the source file and can concentrate on the debugging process itself rather than become concerned with the hexadecimal locations involved.

A final and often overlooked factor in choosing tools is the support expected from the vendor. How long is free support provided, or does it cost extra from the outset? What form of support is available? Will the vendor accept only written correspondence to a post office box? Or is communication by voice telephone, facsimile, or modem available? If the vendor offers a toll-free 800 number, can calls usually get through without a busy signal? Is there a group whose sole function is customer support? What hours do the support personnel work? And are they simply telephone message takers or marketers rather than application engineers knowledgeable about the product and truly interested in your problem? Is an electronic bulletin board system available? Is local support available from field application engineers?

CASE tools

Computer-aided software engineering (CASE) tools, which impose a systematic approach on program writing, grow ever more popular as adjuncts to assemblers and compilers. CASE tools enforce documenting and modeling an application from the initial user requirements through design and implementation, and can test for consistency, completeness, and conformance to standards. They help in simulating, organizing, documenting, and generating specifications for the application. They provide facilities for drawing and managing system architectural diagrams, describing and defining functional and data objects, identifying relationships between system parts, and providing annotations to aid project management.

To probe further

For advice on choosing a microcontroller chip, see “How to select a microcontroller” by John J. Vaglica and Peter S. Gilmour, *IEEE Spectrum*, November 1990, pp. 106–109. Tools for improving software development productivity are described in “The case for CASE tools” in the same issue of *Spectrum*, pp. 78–81.

CASE: Using Software Development Tools, by Alan S. Fisher (John Wiley & Sons, 1988), is a useful introduction to CASE. It covers CASE technologies and methodologies, specific CASE tools, and ideas for managing CASE technology.

The magazine *Dr. Dobbs Journal* is an excellent source of information on software engineering topics and tools for advanced programmers.

Microsoft C: Programming for the PC, by Robert Lafore (Howard W. Sams & Co., 1990), covers C as implemented by Microsoft. Appendix F, “The PWB Debugger: CodeView,” is an easy starting point for those interested in learning source-level debugging.

In *Computer Science: An Overview*, by J. Glen Brookshear (Benjamin/Cummings, 1991), Chapter 5 provides a sound basis for understanding programming languages, while Chapter 6 covers the software life cycle.

About the author

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Embedding spectral analysis in equipment

Digital signal processors enable continuous estimates of signal frequency components to be incorporated into a broad range of real-time systems

Ever since fast Fourier transforms (FFTs) came along and made real-time spectral analysis a practical reality, engineers have been finding both new areas in which to apply the technique and better ways to implement it. FFTs are hard at work today in applications ranging from telecommunications, radar, and sonar to vibrational analysis and nondestructive testing. They are doing everything from remotely sensing the thickness of a layer of hot slag in a steel mill to increasing the data-carrying capacity of ordinary telephone lines. Indeed, so valuable have FFTs proven themselves that a good number of digital signal-processing (DSP) chips are dedicated to executing FFT algorithms as efficiently as possible.

More recently, a variety of superior spectral analysis methods has emerged from the research laboratories. Those methods mitigate some of the fundamental problems associated with FFTs—such as the generation of sidelobes and poor resolution of closely spaced signals—yet can profitably run on the same DSP chips as FFTs. They are especially well suited to the latest floating-point devices, which provide the very large dynamic ranges those methods require.

The new analysis methods get their power from the nature of the assumptions they make about the behavior of the signal under study. In theory, the analytical evaluation of a Fourier spectrum requires knowing the signal over an infinite period of time. In practice, therefore, since signals can be observed for only finite periods of time, their spectra can only be estimated. The different estimates made by different methods reflect the different assumptions implicit in their algorithms.

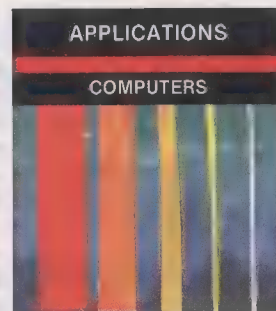
Classical methods

The classical spectral estimation methods are basically algorithms for estimating the power spectral density (PSD) of a discrete (sampled) signal, which is defined as the discrete-time Fourier transform (DTFT) of the autocorrelation sequence of that signal. The PSD describes how the power of a signal is distributed with respect to frequency.

All practical signals have some added noise, which makes them random in nature. For such signals, the PSD is related to the variance through the Fourier transform. A popular method for computing the PSD estimate of a sequence, called the Blackman-Tukey correlogram method, involves forming an autocorrelation sequence estimate from the signal data and then computing the squared magnitude of the DTFT of that data.

If the random signals are ergodic (their time statistics are equivalent to their ensemble statistics), as they often are, then the PSD can be calculated by the periodogram method as the average of the squared magnitude sequences of the DTFTs of many realizations of the random process.

An important consideration in the implementation of classical schemes is dealing with sidelobes, which arise when the sig-



nals have a finite duration. To reduce those sidelobes, the data is weighted by having windowing functions applied to them. Some commonly used window functions are Bartlett, Hamming, Hanning, and triangular. Those functions attenuate the leading and trailing portions of the signal being analyzed and so reduce the effects of signal discontinuities caused by nonintegral numbers of signal cycles.

Each window function has a different effect on sidelobe activity, but all exact a price for suppressing it. Because windows broaden the main lobe, closely spaced sinusoids may not be resolved. The rectangular window (the default whenever a finite data record is analyzed) has the highest sidelobe activity, but as it also has the sharpest main lobe, it offers the best resolution. Choosing an appropriate window for a given application is an art; there is no such thing as a universal best window.

As mentioned earlier, estimation methods differ from each other in the nature of the assumptions they make about how the sampled signal behaves outside the observation interval. The Fourier transform assumes that the signal is periodic outside the analysis window—that the portion of the signal contained within the time series being analyzed is replicated in time to plus and minus infinity. Maximum entropy methods (MEM), in contrast, assume maximum entropy, or randomness, outside the duration of the signal. Still other methods assume that the data is zero beyond the observation interval. To the extent that these assumptions are

Defining terms

AR model: an autoregressive model represented by a system transfer function consisting only of poles.

Autocorrelation sequence of a data record: if $X[n]$ is the data sequence, the m -th lag of the autocorrelation sequence is obtained by summing the product $X[n] * X[n-m]$ over all n .

Bias errors: errors in the estimation of a signal parameter—frequency, for example.

FFT: short for fast Fourier transform, an algorithm used to find the discrete-time Fourier transform (DTFT) of a sequence.

Model order: the number of poles or zeros or both in the system transfer function.

PSD: short for power spectral density, the function of the variance of a random process with frequency, used to describe distribution of signal power in the frequency domain.

Resolution: a subjective term used as a figure of merit for spectral estimation methods—here, a method's resolution is the difference between the frequencies of the closest sinusoids it can separate.

Sidelobes: spurious peaks in an FFT output.

Time-bandwidth product rule: rule of thumb used in spectral analysis stating that the spectral resolution of a signal in hertz is inversely proportional to the observation time of that signal.

Windows: the weighting functions used on data records to modify spectral properties, most often to reduce sidelobes.

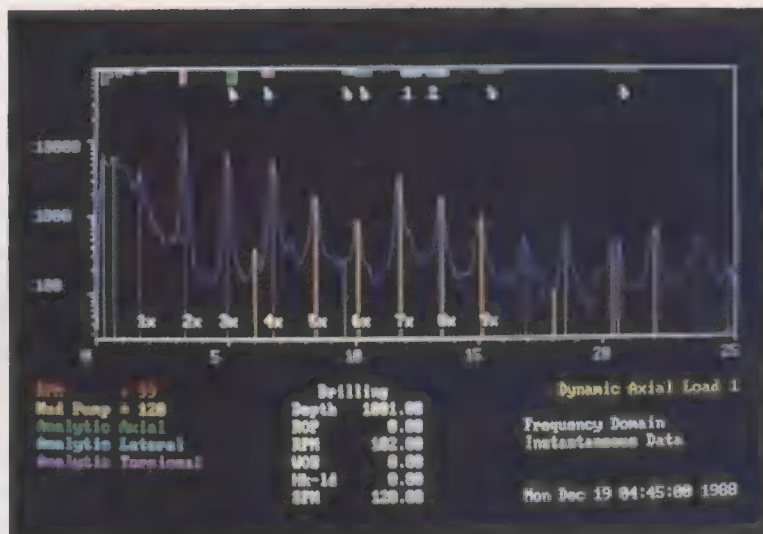
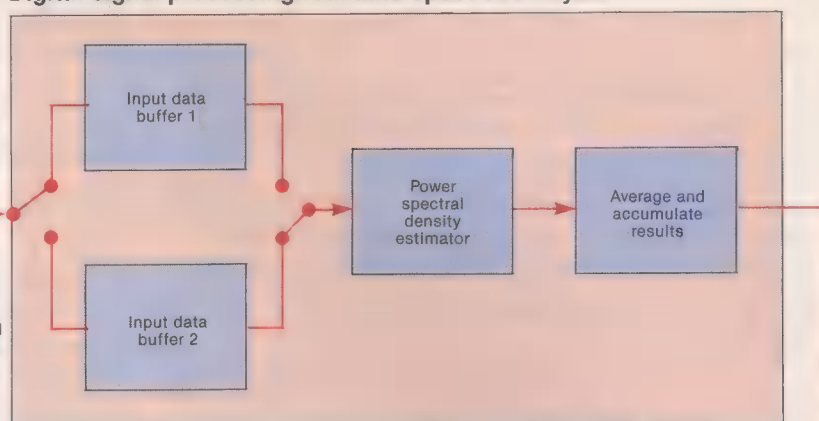
Shrirang Jangi and Yogendra Jain Sonitech Inc.



Exploration Logging Inc. (photos)



Digital signal-processing real-time spectral analysis



This spectral estimation system can be implemented inexpensively on a personal computer with a plug-in DSP development card. Here accelerometers (above) convert vibrations on a drillstring into electrical signals, which are subsequently transmitted to the DSP unit. Spectral analysis results are displayed (right). If the DSP chip has a direct memory access feature, it may be used to load the input buffers and thus speed operation.

incorrect, they lead to a distorted PSD estimate.

In many applications, some knowledge of the process from which data samples are taken is available. That knowledge can be used to construct a model of the process that created the data. Such a model would make a realistic assumption about the data outside the observation interval. That is the intuitive basis for parametric estimation methods, which deliver high-resolution PSD estimates with no need for window functions and their associated problems.

The first step in the parametric estimation of a PSD is specification of the model. A class of models that has been extensively studied are time series models in which the observed data is assumed to be the result of passing a white noise process through a digital filter. The filter's parameters along with the driving noise variance are estimated so that the observed data is the closest fit to the data sequence the filter would generate if driven by white noise. Since white noise is a random data sequence with a flat PSD, the squared magnitude of the system function evaluated over the desired range of frequencies is a good PSD estimate.

Digital filters are described by rational system functions, of

which there are three types: autoregressive (AR), moving average (MA), and autoregressive moving average (ARMA). The AR model assumes that data is created by an all-pole filter driven by white noise. The MA model assumes that the data is created by an all-zero or finite-impulse-response (FIR) filter. The ARMA model is the most general one; it has both poles and zeros.

The term "autoregressive" derives from the fact that the output of an all-pole filter at a given time depends upon regressed, or previous, outputs of the filter, with the number of previous outputs being equal to the order of the filter.

The output of an all-zero filter, in contrast, is the weighted sum of current and previous inputs, with the number of previous inputs being equal to the order of the filter. That, in effect, is a moving average. As might be expected, the ARMA model combines the features of both types.

Clearly, the fidelity of a PSD depends on the accuracy of the process model. AR systems model the sharp peaks in the PSD very well, while MA systems are best at modeling deep nulls. ARMA systems do both very well.

The AR model is the most popular because many computationally efficient algorithms are available for estimating its parameters. Theoretically, an ARMA or MA process can be modeled by an AR model if an infinite-order model is used. In practice, reasonable-sized AR models can approximate ARMA and MA processes to acceptable accuracy.

Fortunately, one of the most common reasons for carrying out real-time PSD estimation is to detect the existence of periodicities in the data. Here the objective is not to calculate an accurate PSD, but simply to detect any sinusoids in data and to estimate their frequencies—just the job for the AR model.

The single most popular method for estimating the AR coefficients is the Burg method, which recursively estimates the parameters for an m -th order system from the known parameters of an $(m-1)$ -th order system. The parameters at each stage of the recursion are estimated so as to minimize the arithmetic mean of the forward and the backward prediction errors with respect to $a[m]$ the m -th coefficient of the AR model.

The Burg algorithm has a complexity of the order $N \times M$, where N is the length of the data record and M is the order of the AR model filter. The algorithm's key advantages are high computational speed and high spectral resolution [see illustration, p. 43]. (It also generates filter functions guaranteed to be stable, but that is not of much use for the method discussed as a PSD estimator.)

The Burg algorithm demonstrates some problems of bias in frequency estimation and line splitting. If the data consists of a sinusoid plus noise, the algorithm will show some error in the frequency estimate depending upon the initial phase of the sinusoid. Also, if the noise level is high, or if the chosen model order is too great, a split peak indicating two sinusoids will appear where only one frequency in fact exists.

These problems are rectified by the somewhat similar modified covariance method. It minimizes the prediction errors with respect to all AR coefficients $a[0]$ to $a[m]$, not just $a[m]$ alone. All the same, many users preferred the Burg algorithm for its superior speed until S. Lawrence Marple Jr. of Orincon Corp., San Diego, Calif., introduced a fast algorithm that made the modified covariance method as computationally efficient as the Burg method. Marple's algorithm has the same computational complexity as the Burg method— $N \times M$ —for model orders that are small compared with the data size. Marple's method is in fact faster than the Burg algorithm.

Selecting the model order

Choosing the correct model order is a major issue in AR modeling. There is no simple way to calculate the best one for a given situation. Some selection criteria do, however, exist in the literature—typically functions of such parameters as the estimated noise variance and data record length. The most popular of them is called the Akaike information criterion.

In practice, no matter which guideline is used, some experimentation will almost always be necessary before an optimal order can be chosen. A good rule of thumb is that the model order should be less than one-third the size of the data record. Also, it should be at least twice the number of expected sinusoids since each sinusoid is modeled by a pair of complex conjugate poles in the system transfer function.

Once the AR coefficients are estimated, the PSD can be computed over the desired range of frequencies by evaluating the squared magnitude of the system transfer function. If the PSD is desired over the entire possible range of frequencies, the most efficient method is to compute the reciprocal of the squared magnitude of the FFT of the AR coefficients. For the ultimate in efficiency, a logarithmic representation of the PSD should be chosen. That way, the divisions necessary for computing the reciprocal can be carried out simply by changing the signs of the logarithms.

Sonitech has done real-time implementations of AR methods on its TMS320C30 DSP processor-based Spirit-30 PC, VME, and S-bus plug-in cards. The timings for a Burg algorithm, modified to reduce bias and line splitting, for order 5 and data record length 64, was 0.6 millisecond. The modified covariance algorithm for the same parameters took 0.51 ms. Hence signals with sampling rates up to 128 kilohertz can be analyzed in real time.

These timings are very encouraging for the audio and vibrational analysis community, which can now implement real-time systems inexpensively using AR PSD techniques. Indeed, some systems of this kind have already been implemented.

The methods described so far all operate on blocks of stored data, and hence are called block algorithms. A class of methods

called sequential algorithms updates the AR coefficients upon the arrival of each new sample from a data acquisition system. Two such methods are the least mean square (LMS) and the recursive least squares (RLS) updates.

LMS is slower but computationally simpler. RLS adapts very quickly to changes in the spectral characteristics, but has poor stability and is computationally intensive. The fast multiplier-accumulators and circular buffer addressing available in modern DSP chips make it possible to implement LMS updates very efficiently.

Implementation on DSP chips

The availability of fast floating-point DSP processors, such as the Texas Instruments TMS320C30, the AT&T DSP32C, and the Motorola 96000, has simplified enormously the real-time implementation of classical spectral analysis methods. All those methods use some form of FFT algorithm, and DSP processors are optimized for executing FFT and filtering algorithms. For example, the TMS320C30 is able to compute a 1024-point complex FFT in 3 ms.

Spectral analysis is said to be real time if a data record takes less time to analyze than to acquire. With the current generation of floating-point DSPs, real-time implementations are easily possible for sampling rates up to 200 kHz.

A typical real-time spectral estimation system based on a DSP chip maintains two buffers in the DSP memory, one each for acquiring and processing data. Data may be loaded into one buffer using the direct memory access (DMA) feature built into many DSP chips even as data in the other buffer is being processed for a PSD estimate. The squared magnitude results of each frame of data are averaged with previous results and accumulated in the results buffer.

Such a system can be implemented inexpensively on an IBM PC using a plug-in DSP card, which contains a DSP chip, dedicated high-speed memory, and interfacing circuitry for the PC bus. The DSP card can also compute the final pixel rendering of the PSD results for the host machine to upload periodically for graphical display.

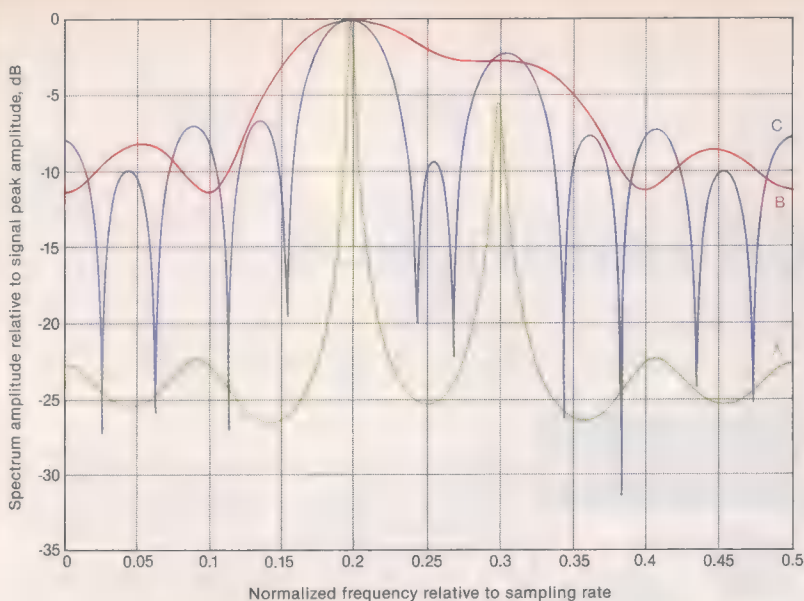
The latest floating-point chips are well suited to implementing more advanced spectral analysis methods. Like general-purpose computers, these new processors support high-level language (C) optimizing compilers while providing special features designed to speed the execution of popular signal-processing algorithms.

The chips are optimized for such operations as filtering, vector arithmetic, and FFT calculations. Often their manufacturers offer efficient assembly language programs for those tasks. It is therefore a good idea to organize any other algorithms in such a way that they can call those tested and efficient programs as subroutines. For example, the FFT may be used to compute autocorrelations, and a filtering program looks very like an LMS update algorithm.

Exploiting DSP chip architectures

DSP chips are characterized by the presence of multiple buses and memory systems. Multiple-operand instructions are therefore executed most rapidly if the operands are fetched via separate buses. Speed is similarly enhanced when component data arrays in the algorithms are mapped to appropriate memory blocks. As an example, in a recent implementation of the Burg algorithm with a Hamming window on a TMS320C30, bus conflicts were minimized by mapping the forward and backward data arrays into on-chip memory; placing the Hamming window weights into the memory connected to the peripheral bus; and keeping the program in the main-bus memory.

A key consideration in real-time implementations is how to manage data acquisition. For DSP chips that support DMA, it is possible to acquire data without increasing the DSP processor overhead by initiating DMA cycles on interrupts from the data acquisition device. The buffer that holds the acquired data should



The high spectral resolution and low sidelobe activity of the Burg algorithm (A) are evident in this comparison based on simulated data. The other two curves are both based on Blackman-Tukey correlograms, one with a Bartlett window (B) and one with a rectangular window (C). The rectangular window resolves the two sinusoids almost as well as the Burg algorithm but shows very high sidelobe activity. The Bartlett window suppresses the sidelobes but barely resolves the two frequencies. The horizontal axis is normalized with respect to the sampling rate.

be mapped into whatever memory will cause the least bus conflict so that data acquisition slows processing down as little as possible.

Some applications

The availability of reasonably priced programmable hardware and the development of sophisticated new software techniques are inspiring designers to use spectral analysis in innovative ways. The small sampling that follows gives some idea of the range of applications possible. The examples are all based on floating-point DSP chips and were implemented with DSP development boards that plug into personal computers or workstations. This use of off-the-shelf hardware freed the designers to concentrate on programming and sped prototype development.

A system for monitoring vibrations in nuclear reactors is being developed by the Netherlands Energy Research Foundation. It uses AR techniques to estimate not only the PSD but also system parameters such as damping ratio and impulse response. The results constantly update a graphical display and are compared with alarm conditions to give early warning of potential danger. The inexpensive portable system uses an AT&T DSP32C processor and an IBM PC-compatible computer. A faster implementation based on the TMS320C30 processor is under way.

Another vibration-monitoring application is called Adams, for advanced drillstring analysis and measurement system. It is marketed by Exploration Logging Inc., Houston, Texas, and the ARCO Oil and Gas Company in Dallas. Adams monitors the vibrations of a multicomponent pipe called a drillstring, which is used in drilling oil and gas wells. Accelerometers and strain gauges mounted on the drillstring convert the mechanical vibrations to electrical signals that are transmitted over a microwave link to a portable system consisting of a personal computer with a TMS320C30-based plug-in card. The system software filters the incoming signals, and the resulting frequency data is displayed graphically every 5 seconds to the Adams operator. The data allows the operator to monitor the buildup of resonance in the drillstring, which can lead to premature drill-bit wear and/or drillstring damage—typically several hundred thousand dollars—if not kept under control.

An unconventional application developed for Special Control Systems Inc., Cleveland, Ohio, measures the thickness of slag layers over molten steel. Because of the intense heat, the measurement is carried out remotely, by bouncing a signal with linearly increasing frequency (a chirp signal) off the slag film. Reflections from the front and the back of the slag film lead to a phase signal, consisting of two closely spaced sinusoids, whose frequen-

cy difference is proportional to the slag film thickness.

Because the data records are extremely short (only five cycles long), the necessary resolution could not be achieved using classical techniques. The Burg method worked well except for bias errors due to uncertainties in the initial phase. Finally, the modified covariance method gave satisfactory results.

Loral Corp.'s Defense Systems Division in Akron, Ohio, designed a system for the Defense Advanced Research Projects Agency, Arlington, Va., that classifies underwater sounds in real time with a neural-network classifier. The noisy signals needed some preprocessing to extract their characteristics before feeding them to the neural network. Periodograms and AR analysis using the Burg method were tried, among other techniques, and the Burg method was found to perform best for the short-duration periodic signals that are typical in underwater work.

Clearly, spectral analysis techniques have matured enough to enter the engineering mainstream, while fast yet inexpensive hardware is available for implementing them in real-time applications. The development effort is no longer prohibitive for designers with limited budgets. A boom in the use of these techniques is surely to be expected soon.

To probe further

A historical perspective of spectrum estimation is to be found in a paper with that title by Enders A. Robinson in the *Proceedings of the IEEE*, Vol. 70, September 1982, pp. 885-907.

An excellent source for spectral analysis methods along with comprehensive computer code is a 1987 book by S. Lawrence Marple, entitled *Digital Spectral Analysis, with Applications* (Prentice-Hall, Englewood Cliffs, N.J.).

Windowing techniques are discussed by F.J. Harris in "On the use of windows for harmonic analysis with the discrete Fourier transform," *Proceedings of the IEEE*, Vol. 66, January 1978, pp. 51-83.

DSP chip manufacturers publish application notes with design examples.

About the authors

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The case for object-oriented databases

Based on relationships inherent in data, rather than on records, new database management software enhances the traditional attributes of DBMSs without surrendering interactivity

Database management systems (DBMSs) have made a big splash in traditional data-processing applications, but in design automation so far they have made only a small ripple. The reason is simple: electronic design automation (EDA), as it moves to support groups of engineers working in tandem, demands very different support from ■ DBMS than does traditional data processing.

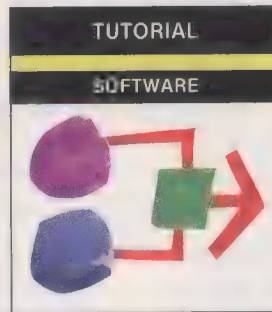
Object-oriented DBMSs, however, which are the third and latest wave of database technology, are attracting the attention of the EDA community. Whereas their predecessors view the world as composed of records, they see it as made up of "objects," entities defined by their functional characteristics. This key difference suits object-oriented technology admirably to EDA applications, as soon becomes apparent from an examination of how it overcomes the three problems EDA presents for database management—modeling data, providing interactivity, and supplying versioning and configuration control. Many in the industry expect that object-oriented databases will be rapidly accepted over the next few years. According to International Data Corp., of Framingham, Mass., the market will grow from US \$20 million in 1990 to \$270 million by 1994. Most of that revenue will come from systems based on workstations and high-end personal computers.

In other fields, commercially available DBMSs have solved the problem of sharing and distributing large interrelated databases. For corporate accounting systems, for example, relational DBMSs work well because the items to be stored and managed—spreadsheets, payrolls, and other accounting systems—fit their record-oriented data model.

An EDA application engineer wants to enjoy all the benefits of a DBMS—data sharing, data distribution, and data integrity—without losing the high degree of interactivity traditional in EDA tools or being forced to program around the DBMS. To provide this full menu of functions, the data structures of the DBMS must reflect the ways in which engineers work and the kinds of information with which they work. In addition, the DBMS must support two new functions vital to a group's ability to collaborate: versioning, which is control over multiple versions of product design data; and configuration control, which is the management of the resources—designer, design data, and design tools—to ensure smooth development.

Evolution of a species

Before database management systems were developed, applications managed data stored in application-specific files. Even though different applications might manage some of the same data, the data was kept in separate files, and so its consistency became hard to ensure. For example, ■ company might have an accounting system with the name and address of a client in one file, ■ customer service system with the client's name and address



in another file, and so on. If the client changed addresses, the company would have to make sure that the department in charge of each system affected by the change was notified and that each updated its files correctly. This would involve a good deal of extra effort and record-keeping on the part of the company.

Database management systems were created to simplify the job of developing applications and ensuring data consistency. The DBMS took over the

responsibility for:

- Arbitrating the sharing of files among users.
- Ensuring data integrity and recovery in the event of problems.
- Distributing data in a network.
- Managing the search through large amounts of data.

Defining terms

Blob: short for binary large object, a variable-length field within a relational table.

Class: in object-oriented programming, ■ user-defined data type that contains data elements, which may be of different types, and ■ set of operations to manipulate the data.

Collection: an object, such as a set, bag, or list, that serves to group together other objects. Each collection is an instance of one of the classes in a collection class library, or else it is an instance of a user-defined extension to this library.

Concurrency control: in ■ distributed system, a means of maintaining data integrity while allowing users to share data in a consistent way so that statements executed within the same transaction run as if executing against a dedicated database.

Configuration control: the ability to flexibly link particular versions of tools and data into a set so that users permitted to use the set can access it whenever they need to.

Database: ■ means of storing information whose existence extends beyond the lifetime of the process that created it.

Direct acyclical graph: ■ graphical representation consisting of arcs and nodes in which the arcs connect the nodes, have direction (based on hierarchical relationships), and do not form a closed loop.

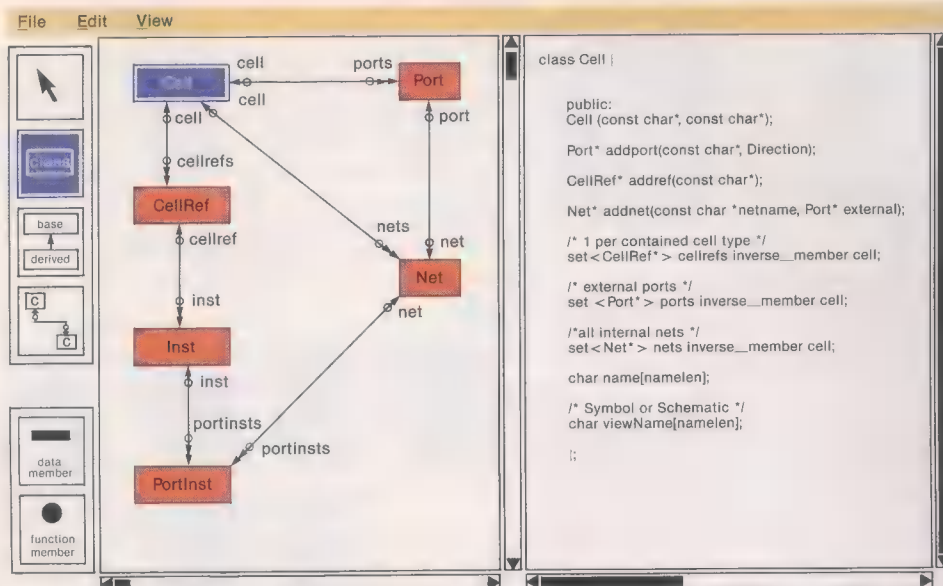
Inheritance: ■ way of specifying one object as a variation of another in which the capabilities of the original object (parent) are passed on to the variation (child), which can augment or override them.

Primitive: an element of a computer language, such as a word or symbol, that implements a basic function that is a fundamental part of the programming approach embodied in the language.

Single-level storage: the ability to represent data structures as if they were in local memory, thereby eliminating multiple levels of translation when addressing objects.

Versioning: the ability to maintain separate versions of data and tools so that any version can be easily recalled when needed.

Thomas M. Atwood Object Design Inc.



[1] In an object-oriented environment, the relationship between different objects, such as "Cell" and "Port," must be defined clearly. Using a relationship facility, such as the one shown here, the Cell can be defined as having an inverse relationship to Port, so that if one object is deleted, the relationships will also be deleted.

ever, objects and relationships behave differently; in particular, their "delete" and "create" semantics differ. For example, a general object, say, a transistor, might be used in a board design. If it is decided that the transistor is no longer needed, the relationship to other board components (objects) should be deleted, but the general object for the transistor should remain in the database.

Because the earliest demands for database management came from transaction-oriented users, such as corporate accounting and customer service groups, the first two waves of database management systems—hierarchical and relational—were designed to support alphanumeric data formatted into the kind of record-oriented files these activities use.

Modeling data

In general, electronic design methodologies tend to create components (in the broadest sense of the word) that are recursively composed of subcomponents. For example, a board may be populated with CMOS chips, each of which may be composed of various registers, whose cells are configured from n- and p-channel transistors. By using such a hierarchical structure, called a composition hierarchy, an EDA system lets a part be built out of a series of references to subordinate parts. The ability to handle such relationships easily and quickly is the key to handling electronic designs.

Fundamentally, traditional database systems lacked the power to model the types of information generated through all phases of product design. In both hierarchical and relational DBMSs, some conventional wisdom evolved about how to use the primitives of the data model to model real-world objects and the relationships among them. Objects were modeled as record types and their attributes given in fields within a record. Relationships were modeled as sets of data types or, in the relational model, by placing keys in separate but related data elements. These keys were used at runtime to join the separate data elements and thereby recover the relationships.

This direct mapping thus had some shortcomings. It did not work for anything more than the simplest of cases, for instance, board designs with a few relatively simple components. Tuples (records) in the relational model were flat collections of "fields," that is, for example, the name of the component (such as RESISTOR), its value, and the location of its leads. The collection of fields could not handle structured attributes, such as a component hierarchy, when, for instance, a network is composed of several different types of components and interconnections that have different electrical properties at different frequencies.

(By the time EDA had developed to the point where data management became an issue, relational databases had pretty much supplanted the hierarchical types. So it is relational databases, not hierarchical ones, that have become a factor in EDA.)

The problem with the mapping of real-world relationships into tuples is that the relational model uses a single primitive for handling both an object and its relationship with other objects. How-

tics cannot be captured cleanly in the relational data model, it has to be reintroduced. This is done either by creating a set of "constraints" or "rules" with which the database designer annotates the description of his data or (worse yet) as a set of conventions that each programmer who uses the database must learn and follow. So it becomes extremely awkward to use a relational database, which has restricted its use for EDA applications.

Another problem arises when EDA systems built on relational databases must join data elements in the program memory to reconstruct the relationships. The EDA system must read the appropriate chunk of the database at start-up, and then use it to build internal record and pointer structures in virtual memory. Therefore, to start a design session, one part of a disk must be copied to another part. Because it must map complex design objects into memory, the relational database is too slow for use in interactive EDA applications.

In a major break with the record-oriented models, the object-oriented model is based on defining and understanding the relationships between objects [Fig.1]. In such a relationship, objects pass data back and forth; and to define the relationship, the nature of the data, rather than the actual data, is examined to understand how an object uses it.

An easy way to model relationships among objects is to use a relationship facility (if the database system has one), which models one-to-one, one-to-many, and many-to-many relationships among objects. With it, the user can constrain the members of the relationship to be consistent with one another.

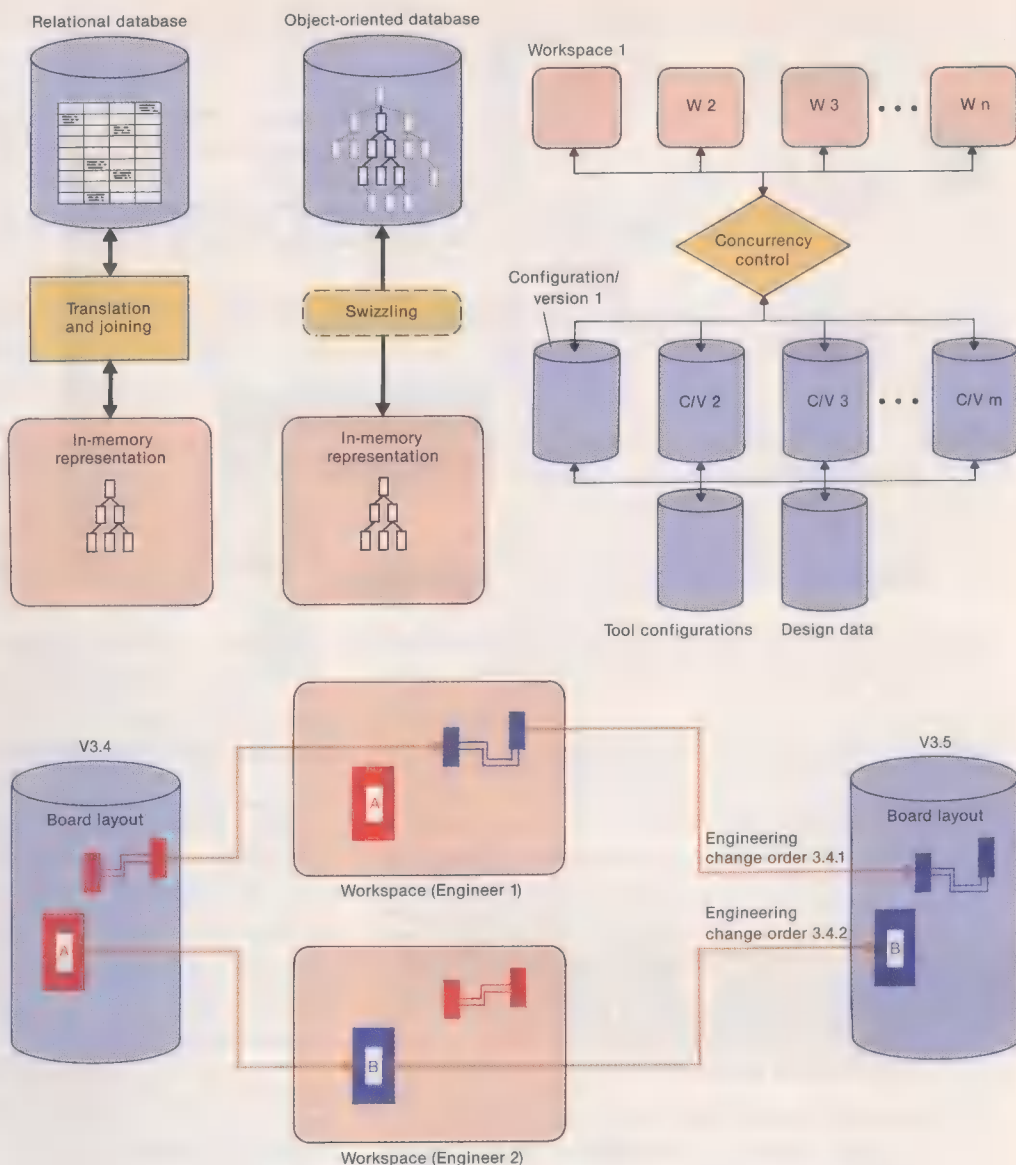
Through a relationship facility, the object-oriented DBMS maintains the integrity of relationships declared by the user. For example, the user can declare two objects to be inverses of each other, and the relationship facility can automatically enforce their dependency when either object is updated. When an object is deleted, the relationship facility automatically deletes the pointer that indicates the inverse relationship to the other object.

The performance hurdle

Historically, engineering design applications have been so highly interactive that storing data in files was the only option. With a file-based system, when a design engineer identifies the schematic to be worked on, the application reads blocks from the file containing the on-disk representation of that schematic and translates the file data into the representation used by the workstation's graphics generator and places it in local memory, that is, RAM.

Typically, the RAM representation is based in some way on a directed acyclical graph. Nodes of this graph are typically C language data structures and arcs between nodes are C pointers. By

[2] To represent a circuit in a workstation's local memory, separate records must be translated and linked with a relational database (top left). An object-oriented database, however, preserves the relationships as they appear in local memory so that addresses need only be mechanically adjusted, or swizzled, to give full access to database representations (top middle). From a workspace—a conceptual space defined by the user or the user's manager in setting up access to the database—any user can pull up tool configurations and design versions to which he or she has been granted access, regardless of who else might be using them (top right). Concurrency control, while shown as a single centralized function for convenience, does not become a bottleneck but functions simultaneously on multiple requests for access, letting multiple users work on the same version of a design in parallel. Thus engineer 1 can change circuit wiring while engineer 2 changes a component. Each can implement a separate engineering change order (ECO) for version 3.4, and both ECOs will become part of version 3.5 when changes are complete (bottom).



traversing the directed acyclical graph, the workstation's graphical display system is able to paint the schematic on the screen. Changes made by the designer using mouse clicks on a screen representation are mapped back to changes in the acyclical graph.

Once the design session is over, the graph is "flattened" (that is, the RAM representation is translated into the on-disk representation) and written back to disk file storage. One significant problem with file-based systems is that, to maintain separate versions of a design (version control), the only approach is to create an entire new file and use an extension (such as ".r1") to indicate the revision number.

Still, the proliferation of electronic design applications that rely on file-based data management means that the speed at which they retrieve data structures has become a de facto performance benchmark. So, while engineers and designers applaud the additional functionality of a database system, they balk at paying a performance penalty for that functionality. This has been the biggest challenge in building DBMSs for electronics engineers.

For a relational DBMS, an obvious approach would be to let records represent the nodes of the directed acyclical graph, and the relationships between records represent the arcs. Unfortunately, traversal of a relationship between two records in a DBMS can take 10 000 instructions and generate significant disk I/O. Thus it would be far slower than using the C data structure employed by the existing single-user tools.

The only way to use a relational DBMS in an EDA system is to store entire designs in binary large objects—Blobs—and then write additional code to extract the direct acyclical graph from information packed linearly into the Blob. The application can run all interactive portions of the design session against the graph's data structures, then pack these back into the Blob.

Essentially, this scheme uses the DBMS as little more than a file, so that it encounters many of the same problems found in file-based systems. For one, the granularity of the Blob or file (that is, the portion of the design it contains) defines the granularity of sharing. Nor does this approach allow different users or tools to work with different representations of the same data.

The first generation of object-oriented systems, although they have the modeling power to represent the structures of a directed acyclical graph, are still too slow to handle the graph's individual nodes as objects. Applications are still forced to map the entire in-memory graph into large "objects" that can be stored in the database. This results in the same kind of constraints as the relational, Blob-based approach. Database relationships can be defined only between these large objects.

There are two approaches that can be used in an object-oriented system to speed the interactivity of the database. Objects can refer to subcomponents by identity (for example, the component name), rather than state (that is, the relational key) of the relational schema, thereby removing one level of mapping. However,

er, the remaining level of mapping—from object identifier to main memory address—still makes ■ system run more than ten times slower than if it directly addressed a memory location.

To reduce the speed penalty associated with this mapping, global object identifiers can be swizzled (translated) into local memory addresses when an object resides in main memory [Fig. 2, upper middle]. Second-generation object-oriented DBMSs provide the capability for swizzling pointers easily, in effect letting a programmer treat the database as a very large, single-level, virtual memory. In this way, the DBMS can handle objects of any granularity with speeds approaching file-based systems.

Benchmarking

In most electronic design or engineering applications, the user reads the design into memory from disk and then works on the in-memory design for several hours before writing revised data back to disk. This being the case, performance of an object-oriented DBMS is best measured by how fast it traverses a large set of RAM-resident objects, rather than how long it takes to move from disk to RAM.

A number of independent evaluations of the commercially available object-oriented DBMSs are under way. The Cattell Benchmark, created by Roderick Cattell, a principal engineer at Sun Microsystems Inc., of Mountain View, Calif., is the best known and most widely accepted by specialists in this area, and it is soon to be formally published, ensuring even wider acceptance. Using his benchmark, Cattell has evaluated four commercial object-oriented DBMSs, as well as two traditional DBMSs.

Of the many operations tested, the one most representative of EDA operations is that of warm traversal numbers (which measure how fast the database can traverse a fixed number of RAM-resident objects once the system is "warm," that is, once a design has been called into local memory). The results of Cattell's test showed significant performance differences, up to two or more orders of magnitude, among the six systems tested for warm traversal.

A new function

Data modeling and interactivity were existing DBMS capabilities that had to evolve for EDA applications. Managing different versions of a design and different configurations of tools, on the other hand, is an entirely new function for database technology. It is, in fact, ■ relatively new requirement in EDA systems.

Computer-aided design tools were first designed to support an individual engineer working on a discrete project. With this model, the tool configuration was likely to be set at the beginning of the project and remain unchanged. And, since the individual engineer had his own files, he controlled which version of the design was used or distributed.

Today, concurrent engineering demands that a design environment be able to support cooperative work by a networked group of professionals. Here, an engineer must be able to create new versions of existing components without overwriting someone else's work, or work on a design without being preempted by someone else's work in progress. He or she also must be able to work with a consistent set of design tools.

An object-oriented DBMS supports collaborative work by granting a team member access to others' work-in-progress. Users can check out an object (or group of objects) at the same time as another user, saving their changes or merging them into the same version of the object.

The support of collaboration and the management of tool configurations are based on three object-oriented DBMS conceptual constructs: configurations, workspaces, and no-conflict concurrency control [Fig. 2, upper right]. Configurations are objects, groups of related objects, or complete designs that are treated as one version of a design. They refer not only to the actual design data, but to the tools used for the design. Workspaces are computer environments, much like an on-screen "desktop," in which an engineer can access, use, and update configurations.

Concurrency control allows two or more engineers to work on the same area of some object.

Here are some questions to ask yourself when evaluating the usefulness of a database management system for EDA:

- How does ■ particular DBMS affect overall system performance, compared to the performance of my existing proprietary file system and other database management systems?
- Does the DBMS offer the functionality required without trading performance or increasing the complexity of development? Do my applications remain highly interactive? Do I have tools like ■ browser and debugger to support development, and does the system support dynamic linking?
- Can I take advantage of the DBMS without losing my investment in my current application software? Alternatively, can I readily convert my existing code for use with the DBMS?
- Does it support ■ standard object-oriented programming language, such as C++, and does it permit the database to be queried in a nonprocedural, optimal way?
- Does it support transactions typical of EDA applications, such as extended transactions of long duration? Does it support version and configuration management?
- Does it offer complete DBMS functions, such as concurrency, restart/recovery, and support for a distributed environment?
- To what extent does the database intrude on my applications? What explicit database operations must I include in my code?
- Will the database support industry standards in operating systems, graphical user interfaces, programming environments, and PC and workstation architectures?
- Is the database designed to support networked client/server computing, the most commonly preferred architecture for EDA?

After making these comparisons, an engineering team involved in a major project should begin a pilot program to assess in full how suited a given DBMS is to the team's requirements.

To probe further

A fundamental text on object-oriented topics is *Object-Oriented Concepts, Databases and Applications*, edited by W. Kim and V. Lochovsky and published by Addison-Wesley, Reading, Mass., 1989. Chapters are contributed by experts in the field, and the one called "Making Database Systems Fast Enough for CAD Applications" by David Maier is of particular interest for its discussion of interactivity requirements.

Many excellent papers can be found in the proceedings of conferences on databases and computer systems. Among them are "Language and Methodology for Object-Oriented Database Environments," by P. Wegner and S. Zdonik from the *Proceedings of the Nineteenth Annual International Conference on System Sciences*, Honolulu, Hawaii, January 1986, and "Benchmarking Simple Database Operations," by W.B. Rubenstein, M.S. Kubicar, and R.G.G. Cattell, which is to be found in the *Proceedings of the ACM Sigmod International Conference on Management of Data*, May 1987.

A brief history of the early development of object-oriented databases for electronic design automation is given in "Design Evolution and History in an Object-Oriented CAD/CAM Database," by G.S. Landis, to be found in the proceedings of the *31st IEEE Comcon*, March 1986, Vol. 86, pp. 297-303. The author has also described earlier requirements for EDA, "An Object-Oriented DBMS for Design Support Applications," in the *Proceedings of the IEEE International Conference on Computer-Aided Technologies (Compint)*, Vol. 85, 1985, pp. 299-307.

About the author

Thomas M. Atwood is chairman of Object Design Inc., ■ Burlington, Mass., developer of object-oriented database management systems that he founded in 1988. He has concentrated in the field of object-oriented DBMS since 1980. The author of numerous technical articles and an active participant in industry standards groups, he holds ■ bachelor's in electrical engineering from Yale University in New Haven, Conn. ◆

Ericsson bets on a cellular world

Sweden's biggest electronics company succeeds in the fastest-growing market in telecommunications, but faces a labyrinth of regulatory and other obstacles

When the Ericsson Corp. received an order to install a cellular telephone network in New York City last October, executives in the parent company's Stockholm headquarters were astounded. Not that the US \$80 million contract was so large—big-ticket items like telephone switches often fetch far more. Rather, it was ■ symbolic coup.

In 1985, Ericsson lost out to Motorola Inc., based in Schaumburg, Ill., in a bid to supply that network's first generation of equipment. But by 1990, the cellular industry had changed dramatically, from systems oriented toward serving customers driving between different regions (cells) within one metropolitan area to network operations offering uninterrupted service to users passing from one city to another.

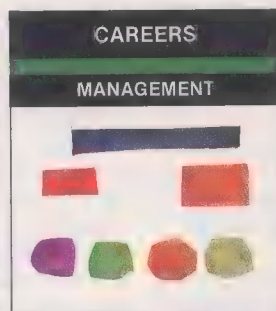
Consequently, when McCaw Cellular Communications Inc. acquired the New York City network late last year, that venture was not only straining under the mushrooming demand for its services. It was also inadequate for the Kirkland, Wash., firm's plans to introduce a digital service and to develop further links with other North American networks. As a solution, the firm decided to update the five-year-old network with Ericsson's AXE digital switch.

For Telefonaktiebolaget LM Ericsson, to give Sweden's biggest electronics company its legal name, the McCaw deal is the frosting on the cake of 15 years of research, development, and redesign of its AXE switch—the backbone of its telecommunications systems and the technological basis for the company's strategy for the next decade.

"The deal was a ringing endorsement of Ericsson's products and a spectacular showcase," Eleanor Buss, telecommunications analyst at London's Robert Fleming & Co., told *IEEE Spectrum*.

As the McCaw deal showed, however, success in today's hotly competitive telecommunications industry has never been more fleeting. The trick will be to reconcile the company's past investments with the current blistering pace of technological change. For Ericsson, the future clearly lies in the area of radio communications. Cellular telephony in particular is flourishing, with approximately 10 million subscribers worldwide. Half of those are in the United States alone, and their numbers are expected to double by 1993 and redouble by 2000 to 20 million, according to the Cambridge, Mass., consulting firm of Arthur D. Little Inc. "Growth in the cellular system is limited only by the ability to put infrastructure in place," said George Verhese, telecommunications analyst at Deutsche Bank AG in London. "The whole world is out there."

Fortunately, the AXE has proved well-suited to the evolution of telecommunication networks toward cellular and other technologies. Because it was designed as a system of self-contained and distinct modules connected by strictly specified interfaces, Ericsson engineers say they have had great flexibility in modifying the switch to adapt to changing demands, offering customers



software that allows the switch to communicate with a database or to hand off telephone calls between cells in a timely fashion, and tailoring the switch to form a platform for new services.

The AXE in many ways expresses the company's culture as much as its technology. Unlike suppliers in larger European countries such as Germany, who have made a good living at home, Ericsson was forced early to look beyond the relatively small Swedish population—little more than eight million

even today. Lars Magnus Ericsson, who as a 30-year-old mechanic started ■ shop to repair telegraph equipment in Stockholm in 1876, began exporting telephones to Norway just five years later—only three years after deciding to manufacture them.

In addition, the company has had the good fortune to supply equipment for what has historically been one of the world's most up-to-date telephone networks. By 1886, for instance, Stockholm boasted the world's highest per-capita concentration of telephones. The precocity of Sweden's telephone network fueled ■ hotbed of competition in telephone equipment manufacturing, and the effort to keep up at home put Ericsson under still more pressure to develop export markets. It began supplying equipment to the Dutch PTT in 1892 and built factories in Imperial Russia's St. Petersburg in 1899, Beeston in Great Britain in 1903, and a suburb of Paris in 1911. And from the beginning of the century on, it took a leading role in building the Mexican telephone network.

With help at home

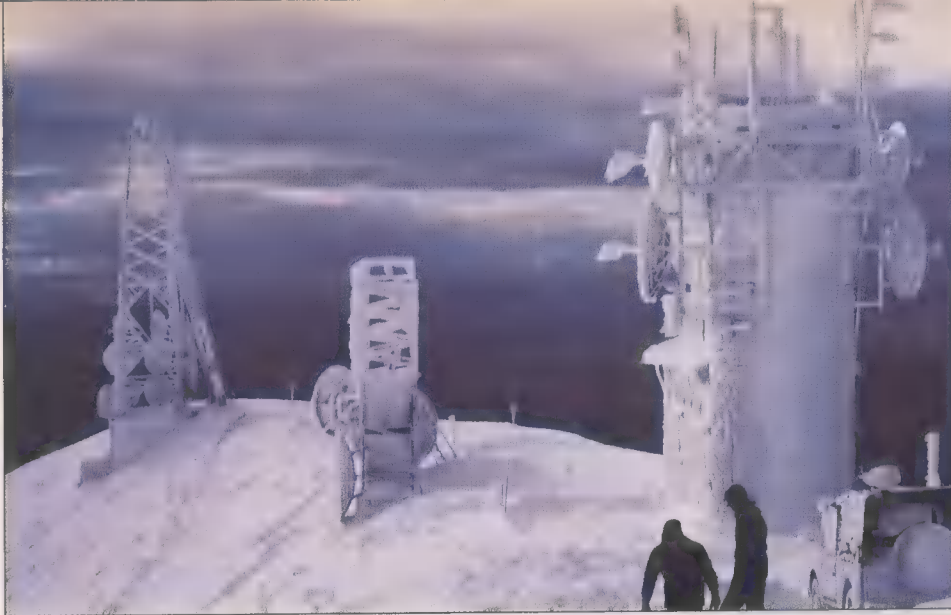
Ericsson still benefits from Sweden's continuing investment in its phone system. The Swedish PTT's support has traditionally included the funding of R&D for developing public switches, such as the AXE. Indeed, much of the initial development of the AXE took place in a joint venture for which the PTT provided 50 percent of the investment. But executives point out that Ericsson financed the design features crucial to success in the export market.

The AXE was developed in the 1970s under Ericsson's previous chief executive, Bjorn Svedberg. An electrical engineer often described as diplomatic, soft-spoken, and almost shy, Svedberg is praised for his stewardship despite having steered the company disastrously into the computer business in the early to mid-1980s. At the time, the technological merging of telecommunications with computers seemed to augur a similar industrial synergy—an illusion that beguiled many electronics firms around the world. Ericsson poured millions into a computer division.

Svedberg quickly realized his mistake, and jettisoned computers, refocused on the core technologies of telecommunications, and raised marketing to strategic equality with them. Lars Ramqvist, who took over as president and chief executive last spring, has accelerated these changes.

"Ramqvist is a very different personality from Svedberg," said telecommunications analyst Buss. "He's aggressive and market-

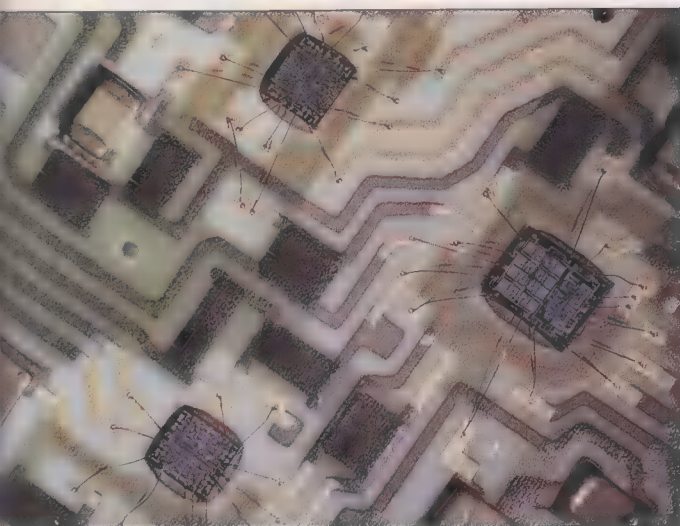
Fred Guterl Correspondent



Ericsson's Military Division, though relatively small, provides an R&D complement. At left is a microwave station for advanced military communications in the Italian Alps.

Ericsson produces only crucial components in-house. One such chip (lower left) is this subscriber-line interface circuit (SLIC), a bipolar CMOS hybrid, here surface-mounted.

Although radar is peripheral to Ericsson's main business, Sweden relies on the company as a domestic supplier, providing such military systems as this on-board radar for the Swedish Navy (below).



ing oriented, and that is a sign of the times at Ericsson."

Significantly, Ramqvist was the architect of Ericsson's most important business, cellular telephony, which has risen from virtually nothing 15 years ago to roughly 25 percent of the firm's 1989 sales of 40 billion Swedish kroner (US \$7 billion). It is the fastest-growing division—sales increased 76 percent in the first nine months of 1990—in a company that now ranks sixth in the world in telecommunications equipment sales volume, behind the Netherlands' Alcatel, AT&T Co., Canada's BCE Inc., Germany's Siemens AG, and Japan's NEC Corp. Ericsson, which employs 70 000 people in its six divisions, now operates in 80 countries.

Cellular roots

Ericsson's involvement with cellular technology began in the late 1970s when the Swedish PTT, true to tradition an ardent investor in novel systems, began discussions with the company over standards for the first international seamless cellular network, one that would span the Scandinavian countries. An order for a state-of-the-art analog cellular system from free-spending Saudi Arabia further fueled development.

Ericsson claims that 40 percent of all cellular telephones in the world are connected to its systems. The company's sales to British cellular-network builder, Racal Electronics PLC, Bracknell, Berks., make it the largest cellular supplier in the United Kingdom, perhaps the most freely competitive telecommunications marketplace in the world. It has also won an order to be the prime supplier to one of two cellular networks in Germany, an important and hitherto closed market. And with the McCaw order

Ericsson becomes No. 1 in the United States in cellular switches. (Motorola leads in sales of terminal equipment.)

Other of Ericsson's recent inroads into the North American cellular market have been substantial. Its joint venture with General Electric Co., Fairfield, Conn., to manufacture and market terminal devices such as hand-held cellular telephones in the United States contributed one-third of the cellular division's spectacular rise in sales in 1990. The AXE, partly on the strength of modifications that have made it suitable for cellular systems, has won orders from five regional Bell operating companies, establishing Ericsson as third vendor with three of them.

Still, with a multiplicity of other technologies vying for acceptance, maintaining leadership in cellular telecommunications will not be easy. Spectacular growth has released a flood of R&D money and a horde of proposals for transmission schemes, interface standards, and so on. A bevy of regulatory bodies—the Federal Communications Commission (FCC) in Washington, D.C., the European Telecommunications Standards Institute (ETSI), near Paris, France, and dozens of national European and Japanese agencies—are reeling under the task of unraveling the technical and political issues, in some cases fielding new technologies that spring up even as they deliberate.

FDMA, TDMA, or CDMA?

The task that Ramqvist and his Ericsson lieutenants face is to pick their way through the technological labyrinth while avoiding too many of the wrong turnings that waste valuable resources. The company must stay ahead of the learning curve while bring-

ing its influence as ■ leader in the technology to bear on the politics of standards making. An adverse ruling could wipe out millions in R&D investment.

On this score, ■ might be expected, Ericsson has been most successful in Europe. Deregulation has made the UK a testbed for new telecommunications services. When the so-called Telepoint service was established there two years ago, Ericsson was skeptical about its long-term success. In the Telepoint system, users place telephone calls with an inexpensive and lightweight portable handset. However, they must stand within about 50 meters of a receiving station, usually located at ■ railroad station or other public spot, and they cannot receive calls. In addition, Telepoint is based on frequency-division multiple access (FDMA), a digital protocol that many believe makes inefficient use of available frequencies because it dedicates a separate frequency channel to each call.

Ericsson engineers certainly opted not to push the technology but instead to invest in the next generation of digital cellular systems based on time-division multiple access (TDMA). In TDMA, a single frequency band carries up to 16 packets of digitized voice data, which are used to reconstruct eight two-way conversations. Last year Ericsson introduced a pocket cellular handset based on TDMA in Europe, and this year it plans to market it through GE in the United States.

Ericsson's efforts seemed to have paid off when ETSI last year ruled in favor of the company's proposal that Europe adopt a TDMA-based scheme for its next generation of digital cellular systems. Admittedly, Germany has begun conducting trials of the FDMA-based Telepoint service, and France and Finland are looking into it as well. But Telepoint in the UK has attracted fewer users than was hoped.

Meanwhile, across the Atlantic, Ericsson has convinced some officials at the Federal Communications Commission (FCC) of the merits of TDMA. But the rest of the cellular industry is flirting with code-division multiple access (CDMA), in which users transmit simultaneously rather than sequentially, as with TDMA.

CDMA is less mature but considered to be more secure.

Ericsson's rival Motorola, long a firm opponent of TDMA, is now backing CDMA for the next-generation U.S. cellular system. Others in favor include three telecommunications regional holding companies—Pacific Telesis, Nynex, and Ameritech. If forced to convert to CDMA technology, sources estimate, Ericsson would lose, at the very least, six months in the marketplace.

Industry uncertainties

Standards are not the only uncertainty that Ericsson faces. The possibilities for new telecommunications techniques are so numerous as to bewilder anyone attempting to forecast industry directions. When the FCC, as a preliminary step to defining standards for personal communication networks (PCNs), recently asked manufacturers to define them, the definitions proposed varied so widely that almost every manufacturer could rightfully claim to have invented the idea.

With finite resources, Ericsson has had to bet on just ■ handful of new technologies. It has embraced ■ next-generation version of Telepoint called CT3 (for Cordless Telephone 3), in which the cells are smaller and less robust than with the existing analog cellular telephone or with the forthcoming digital products. The Swedish company has also been selling mobile data systems, in which handsets and portable terminals receive data from Telepoint-like stations. Trucking fleets are a typical customer. Eventually, Ericsson would tie this system into its CT3 and digital cellular systems, manufacturing handsets that operate in all three environments and could be handed off among the three.

Ameritech recently awarded Ericsson ■ contract to supply a key part of its so-called intelligent network. In the past, information about such things as toll-free 800 telephone numbers has had to be duplicated in local switches. Ameritech's idea is to store it instead in a large central database, making the information far more accessible on its network and thus opening the way to new subscriber services. Ericsson's AXE switch, acting as a control point, will recognize special calls and route them to the database.

MILESTONES

1876 Lars Magnus Ericsson (below) opens a workshop for the repair of telegraph instruments in Stockholm. Alexander Graham Bell files for telephone patent in the United States.



LM Ericsson (photos)

1879 Ericsson manufactures 74 telephones and expands to 10 employees.

1883 Constructs its first factory.

1896 Becomes Aktiebolaget LM Ericsson, with a share capitalization of 1 million kroner.

1897 Opens a factory in St. Petersburg, Russia, for assembly of telephones.

1900 Founder steps down as president and a year later also resigns as chairman, but keeps a seat on the board of directors.

1902 Ericsson opens an office in New York City.

1903 Opens a factory in Great Britain, the world's largest export market, in partnership with a local firm.

1918 Merges with rival manufacturer, becoming Allmanna Telefonaktiebolag LM Ericsson. The company's factory in the new Soviet Union is nationalized.

1926 Lars Ericsson dies at 80 in Stockholm. The word Allmanna is struck from the company's name.

1929 A joint venture agreement is made with the Bell System in the United States for developing Mexico's telephone network.

1932 Ericsson, whose controlling shares had been sold to International

Telephone & Telegraph Corp., faces liquidity crisis. It obtains emergency credits from Swedish and foreign banks, losing 22.7 million kroners for the year.

1950 Delivers its first automatic exchange based on its crossbar system to Helsinki, Finland.

1952 Concludes an agreement with Western Electric Co. for the exchange of patents.

1956 Agrees to cooperate with the Swedish PTT on R&D in electronics for switching.

1960 A Swedish consortium repurchases all of ITT's shares in Ericsson.

1968 Sweden's first stored-program-controlled telephone exchange opens in Tumba.

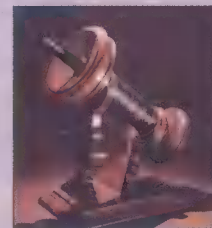
1970 LM Tel, ■ research joint venture between Ericsson and the Swedish PTT, is founded to begin

work on the AXE switch.

1974 The first stage of the British Post Office Corporation's new international telephone exchange in London is put into service.

1985 Profits plunge 44 percent, reflecting troubles in data communications.

1990 Bjorn Svedberg relinquishes day-to-day control of the company to a new president and chief executive, Lars Ramqvist, but remains Ericsson's chairman.



One of Lars Ericsson's earliest telephones.

LM Ericsson business areas and major products

Business areas	Percent of sales	Products
Public telecommunications	43.7	AXE digital switch, TMOS network management system, intelligent network nodes, and intelligent multiplexers
Radio telecommunications	20.4	Digital mobile telephones such as the Hotline Pocket telephone, Mobitex mobile data systems, cordless telephones, and digital tactical defense radios
Cable and network	13.2	Cables for power distribution and telecommunications; planning and installation of telecommunications and data networks and telecommunications plants
Business telecommunications	12.4	MD 110, BCS 90, and 150 PABXs; Eripax packet switch
Defense systems	8.2	Airborne electronics, including radar, thermal imagers, and countermeasures; command and control systems
Components	1.8	Subscriber line ICs, lithium niobate components, power supplies, and cooling subsystems
Other operations	0.3	Energy systems

Source: LM Ericsson

Disappointing sales of PABXs in recent years, however, have underlined the unpredictability of the industry. Whereas five years ago PABXs were thought to be a key to the future, their days are now seen as numbered—to be replaced, perhaps, by radio-based Centrex systems, in which switching hardware resides at the local telephone company rather than in the basement of a firm's building. Ericsson's MD 110 PABX, developed at a cost of hundreds of millions of dollars, has so far failed to live up to expectations, as have competitors' products. Fortunately for Ericsson, it is covered by strong sales of its AXE public switch, which can be the basis of a Centrex system.

In the past, too, Ericsson shied away from selling equipment for the lower extremities of a telephone network—those involving the actual transmission of signals. It preferred the computation-intensive switching aspects. The current trend toward widely distributed intelligence, however, has made transmission an increasingly important piece of the network puzzle, especially for such products as digital cross-connects, which re-route calls dynamically so as to optimize the available capacity of trunk connections. Although revenues from transmission systems are still a relatively small percent of sales, the company has developed its own digital cross-connect and even won an order with the Deutsche Bundespost, the German post and telecommunications authority (PTT).

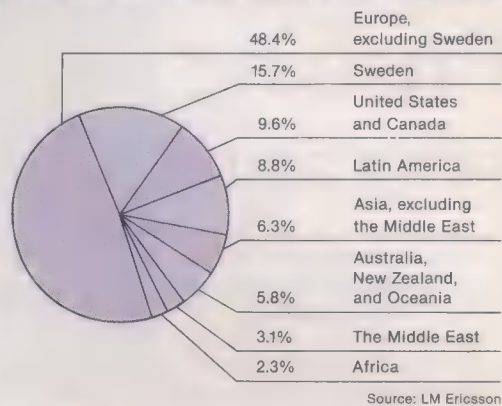
Revisionary R&D

Rising R&D costs work against relatively small and specialized companies like Ericsson and in favor of large diversified companies such as Siemens AG—nicknamed "The Bank" by Ericsson engineers because of its tremendous resources and cash reserves. To keep up, Ericsson's R&D budget has soared to 13 percent of sales, and Ramqvist said it could go higher still.

To render R&D more efficient, Ericsson is continuing a decentralization that began in the early 1970s. The cost of maintaining researchers in Sweden, with its high standard of living, has become more and more burdensome. More important, executives felt that they could get better results by moving both the fundamental and applied research to various divisions of the company, where they could foster a greater interchange of ideas among researchers and development engineers. That resulted in abolishing the central research laboratory in Stockholm.

Last year, however, Ericsson put more rigid boundaries between research and development by forming multidisciplinary groups of 15 to 25 researchers for specific projects. For instance, one group doing applied research in technologies bearing on fiber optics drew on various parts of the company for engineers expert in components, optical switches, and broadband transmis-

Global distribution of LM Ericsson's sales



sion applications. The group is managed by a board consisting of the heads of each division in the group.

Even with a revamped R&D strategy, Ericsson will come under heavy pressure to consolidate with others in the telecommunications industry. It remains one of the smaller players in a field crowded with the likes of AT&T, Motorola, Canada's Northern Telecom, Siemens, Alcatel, Italtel of Italy, and Fujitsu and NTT of Japan. Larger companies can afford to integrate vertically—to make their own components, subsystems, and systems, so as to lower costs and raise profit margins.

Ericsson now forges close relationships with suppliers, to obtain early access to new products and technology—especially crucial in the fast-changing semiconductor field. Three years ago it made an agreement with Texas Instruments Inc., Dallas, under which division heads from the two companies hold quarterly meetings to discuss the technical possibilities for new products for the next three to five years. In addition, Ericsson relies on TI to supply it with computer-aided design software and specifications for the latest semiconductor technology. But since Ericsson buys some of its ICs from Motorola and other firms that also make rival systems products, it still must maintain its own CMOS and bipolar MOS fabrication lines in Stockholm for 50 or so crucial chips.

If Sweden ever joins the European Community (EC), it has been proposed, Ericsson would stand to tap considerable funds available for joint research. Even now, a provision that lets companies from non-EC nations participate in the research itself allows Ericsson to take part in several programs, including RACE for advanced applications of broadband communications technology, and some Esprit programs. Since EC funds are forbidden to Ericsson, however, the Swedish government reimburses it for the costs it incurs.

Yet, if Ericsson is to remain a major player, analysts say, it will have to improve its worldwide balance of business. Although the company recently stopped losing money in North America, where it is the third-ranking telecommunications supplier, it must begin to rake in profits if it is to finance its continued rapid expansion. It also must continue to attract new business in Germany and start to attract business in Japan, where except for a marketing agreement with NTT it has virtually no presence. Further, Ericsson management has remained overwhelmingly Swedish—including every member of its board of directors. In the long run, as Ericsson does more and more of its business overseas, that cannot work in its favor.

To probe further

A three-volume history of LM Ericsson, titled *LM Ericsson: 100 years* and written by A. Altman, J. Kuuse, U. Olsson, and C. Jacobaeus, was published by the company in Stockholm, Sweden, in 1977. ♦

Pushing the limits of standard CMOS

Circuit refinements helped by computer-aided design raise clock rates by an order of magnitude—up to 1 gigahertz in an experimental ripple counter

CMOS technology is excellent for very large-scale integration (VLSI). A wide noise margin, low power consumption, and low cost make it the most suitable IC technology for many applications. Its only limitation has been its comparative slowness.

However, an improved clocking scheme and sharper circuit design and logic selection have yielded a five- to tenfold increase in the speed of standard CMOS ICs. A clock rate of 450 megahertz was measured for an experimental 8-bit register fabricated by combining this technique with a 3-micrometer CMOS process. A 24-bit accumulator in 1.25- μm CMOS clocked in at 700 MHz. A ripple counter in 2- μm CMOS hit an input frequency of 1 gigahertz. [See table and Fig. 1.]

To go into more detail, the newly developed clocking strategy relies on a true single-phase clock, device sizes are varied to optimize their speed, and a precharged logic style reduces capacitive loads. The tradeoff is roughly a doubling of circuit area.

Applications with high data rates and low demands on latency stand to benefit the most. And it should be emphasized that any of today's standard CMOS fabrication processes can make use of the design technique.

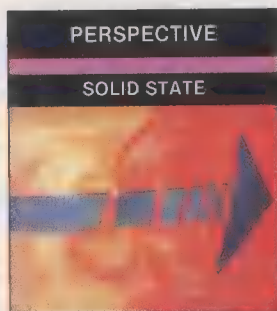
Compared with the gigahertz levels of bipolar or gallium arsenide technology, standard CMOS is slow. Typically, a 2- or 3- μm CMOS chip has a clock frequency no higher than 20–40 MHz. On the other hand, bipolar circuits consume a lot more power, and GaAs ICs cost a lot more money. In short, it would be a significant achievement if CMOS speed could be raised. All ICs are, of course, getting steadily faster as their transistors shrink in size. Still, processes that reduce device dimensions are costly, so it would certainly be preferable to boost speed by just changing the circuit design, as is done by the methods described here.

The technique, applicable to all areas requiring fast clocking, accepts extensive pipelining and is therefore best adapted to simple algorithms. Examples are electronics for optical-fiber communication systems, digital filtering, image processing, digital radio, video (high-definition television), and packet switching, as well as real-time control systems and computer hardware in general.

With this technique, some circuits, till now restricted to bipolar or GaAs implementations, could be fabricated in CMOS. The substitution would reduce cost and system power consumption. Also, it would be much easier to combine high speed with high complexity in the same chip.

Moreover, the route to commercialization of the technique is quite short because of its applicability to any standard CMOS fabrication line. Another plus is that it is robust and easy to learn. A drawback is that it is less effective for complex logic that cannot be pipelined.

Almost all digital systems are synchronized by clocks serving as time references for data operations and communications. In



CMOS technology, a pair of complementary clocks is the norm, being used to obtain nontransparency; that is, so as to keep track of data, each circuit stage should be turned on when the previous stage has already been turned off. This is the basis for the most common timing strategy, the so-called nonoverlapping, pseudo-two-phase clock, which needs all of four clock lines and has dead times between active clock phases.

Limitations here are that clock skews cause a serious problem and that dead times waste time. The NO RACE (NORA) dynamic CMOS technique uses a true two-phase clock and thus avoids some of the problems, though with some constraints on logic composition, such as a requirement for an even number of inversions.

The new high-speed CMOS design technique goes a step further and employs a true single-phase clock, in which only one clock signal is used and is never inverted. Here, nontransparency is obtained in the circuits themselves by extending the use of the precharge principle in combination with CMOS technology. In the absence of a multiphase clock, skews between clocks cannot exist, and fewer clocked transistors are needed. Because fewer transistors give rise to less capacitance and less resistance, the ICs are faster. Other advantages are simplicity in clock driving and distribution, less chip area occupied by clock lines, and flexibil-

Defining terms

Clock: a periodic signal for synchronizing events in a circuit.

Clock skew: unintentional time difference between clock edges; can exist between clock phases or between clock signals in different parts of a circuit.

Complementary clocks: two clock signals with opposite phase.

Dead time: time interval in which no clock phase is active.

Design rule: the minimum allowable line width specified for an IC-manufacturing process.

Latency: data delay between input and output (if more than one clock cycle is involved).

Nontransparency: the inability of data ever to pass a latching stage directly.

NORA technique: short for NO RACE technique, a dynamic CMOS circuit technique using complementary clocks and needing no dead time.

Pipelining: a method of speeding up computation by performing successive computations on successive data simultaneously.

Precharge: a circuit technique in which a node is first charged to a given value, then conditionally discharged to a data value.

SLOP: short for switch-level optimization, a computer-aided design tool developed by the authors.

TMODS: short for time MOS modulator, a switch-level simulator with timing, available to Swedish universities.

Two-phase clock: two synchronized clock signals, active at different times.

Jiren Yuan and Christer Svensson
Linköping University, Sweden

ity in logic composition.

In ■ nutshell, device sizing is the art of trading off area against speed. Most digital CMOS circuits employ just one size of transistor (barring the large ones used as the heavily loaded drivers of long buses or output pads). But if the size of each of its transistors is optimized for speed, the IC in turn becomes much faster.

This optimization process is often quite complicated, for an MOS transistor's dimensions have ■ variety of effects on its speed. The device's driving capability is proportional to its width, and its capacitive loading on the circuit is proportional to the areas of its gate, drain, and source.

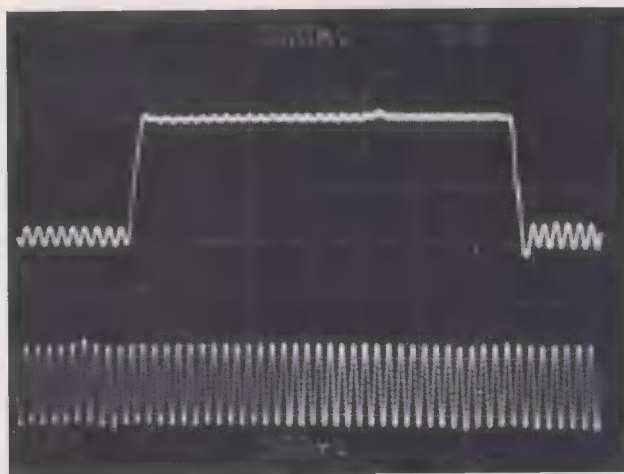
For a large circuit, the behavior of speed as ■ function of device size is so complex that it cannot be figured analytically. The solution was to develop ■ computer-aided design tool called SLOP around a switch-level simulator called TMODES. This tool adjusts transistor widths to speed requirements.

The TMODES simulator models delays as convex functions of transistor widths. Accordingly, it can relatively easily find the best possible widths by calculating zero partial derivatives and comparing different delay paths. The delay improvement varies with circuit complexity, logic style, and area limitation. A typical improvement in circuit speed falls between 60 and 90 percent, with ■ corresponding area increase of 80–110 percent. The tools are readily applicable to general-purpose CMOS circuits.

The speed of a logic circuit depends upon the time needed to make logic evaluations. In ■ synchronized system, circuit speed is always related to the clock rate. The maximum clock rate is limited by the maximum gate delay from one latching point to another. It is also strongly affected by both the logic style and the circuit structure. A precharged logic style, which requires only half as many transistors as static logic, is preferred because of the reduced capacitive loads already mentioned.

The delay of ■ CMOS circuit is quite sensitive to the number of transistors in series. Although device sizing can reduce the delay of a transistor chain, the chain still occupies a large chip area and its delay can never be less than the sum of the intrinsic delays of each transistor in it. In other words, it must be shortened. This means few inputs to each gate and, if possible, AND logic used in p-channel transistor chains or OR logic in n-channel chains. Since an n-channel transistor switches more than twice ■ fast, n-channel logic is always preferred. Logic depth should be as small as possible, and can usefully be reduced by decomposing complex logic into small, pipelined segments. Such decomposition can also be done between half clock-cycles, to exploit both the rising and falling edges of the clock pulse. These principles seem simple but are very effective.

The high-speed CMOS technique has been demonstrated experimentally, with surprisingly good results. Different circuits were designed and fabricated in



[1] A ripple counter in 2-micrometer CMOS fabricated at Linköping University in Sweden operates at 1 gigahertz. Waveforms show the input (bottom) and the output (top) of the sixth stage.

different processes and then tested. Ripple counters in 3- and 2- μm CMOS processes reached input frequencies of 400 and 750 MHz, respectively—nearly 80 and 70 percent of the intrinsic speeds of these processes.

Pipelined accumulators in 2- and 1.2- μm CMOS processes operated at up to 430- and 700-MHz clock frequencies, respectively. The data rate of an error-correcting encoder designed for an optical-fiber communication link was measured as 1.2 gigabits per second, while the corresponding decoder was simulated at the same speed.

A more recent study focused on chip-to-chip communications, a critical element in a high-speed multichip CMOS system.

A single line driver fabricated with ■ 2- μm process achieved 700 megabits per second in tests, while chip-to-chip data transfers simulated in a 1.2- μm process attained more than 1 Gb/s.

In general, the circuits were found to be as robust as any CMOS circuits designed in a conventional way. Direct comparisons have shown better robustness for skew and clock rise time than for circuits designed with the NORA technique.

To probe further

The authors together with I. Karlsson first published their new clocking strategy in "A true single-phase-clock dynamic CMOS circuit technique" in the 1987 *IEEE Journal of Solid-State Circuits*, Vol. SC.22, pp. 899–901. A paper written by M. Afghahi and C. Svensson, "A unified single phase clocking scheme for VLSI systems," generalizes the method and was published in the same journal in 1990, in Vol. 25, pp. 225–233. Device sizing was introduced in "CMOS circuit speed optimization based on switch level simulation" and "A simulation-based fast algorithm for CMOS circuit speed optimization," both written by J. Yuan and C. Svensson, in the 1988 (Vol. 3, pp. 2109–12) and 1989 (Vol. 2, pp. 868–71) *Proceedings of the IEEE International Symposium on Circuits and Systems*, respectively.

About the authors

Jiren Yuan is an assistant professor and Christer Svensson ■ professor in the department of physics and measurement technology at Linköping University in the Swedish city of Linköping.

Yuan was born in 1940 in Shanghai, China, earned a bachelor's of science in 1964 at the Polytechnical Institute in Harbin, China, and received his doctorate from Linköping University in 1989. Svensson, a native of Borås, Sweden, received a 1965 master's of science and ■ 1970 doctorate from Chalmers University, Gothenburg, Sweden.

The work described here began under Svensson's supervision as the basis for Yuan's doctoral dissertation. The article they published on it in the 1988–89 *IEEE Journal of Solid-State Circuits* won that journal's Best Paper Award.

High-speed redesigns of standard CMOS circuits

Circuit	Measured average clock or data rate
With 3- μm minimum line width:	
8-bit register	450 MHz
8-bit ripple counter	400 MHz
16-bit half-static divider	350 MHz
Serial full adder	225 MHz
8-bit synchronous counter	200 MHz
Encoder for analog-to-digital converter	200 MHz
8-bit successive-approximation register	200 MHz
With 2- μm minimum line width:	
8-bit ripple counter	750 MHz
24-bit accumulator	430 MHz
75-ohm line driver	700 MHz*
Bit-serial sorter	400 MHz
With 1.2- μm minimum line width:	
24-bit accumulator	700 MHz
Optical communications encoder/decoder	1.2 Gb/s

*simulated

A streetcar named Light Rail

Faster than buses and much cheaper than rapid transit systems, light rail transit is catching on in North America... again

Rail transit is undergoing a renaissance in North America, particularly in the United States. U.S. cities, after pioneering the use of electric streetcars or "trolley" cars in the late 1800s and early 1900s, abandoned most of them in favor of buses and automobiles by the end of World War II [see "The evolution of streetcars in the United States and Europe," p. 55]. But today's concerns about automotive traffic congestion and air pollution have renewed U.S. interest in light rail transit (LRT) systems, the streetcar's modern successors.

That interest began in the 1960s when U.S. city and transit-system planners became impressed with the efficiency and reliability of modern tram systems in Europe—and the way they blended unobtrusively into their surroundings. It was furthered in the early 1970s by a growing appreciation of the enormous costs and long lead times associated with such conventional rapid rail metro systems as the San Francisco Bay Area Rapid Transit system (opened in 1972) and the Washington Metropolitan Area Transit Authority system (opened in 1976).

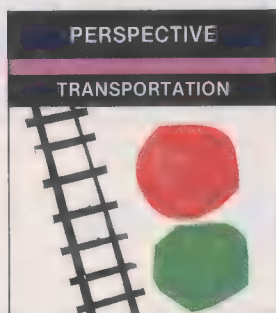
The early 1970s also witnessed major vehicle replacement programs by the San Francisco Municipal Railway and the Massachusetts Bay Transportation Authority in Boston—the first streetcar purchases made in the United States since the early 1950s.

What exactly is light rail?

Although modern light rail systems are clearly descended from streetcars and interurban electric railroads, they differ significantly from them and from high-capacity rapid rail transit systems. The dissimilarities are in three main areas: the degree of separation between their tracks and other traffic, vehicle technology, and operating practices.

A key defining feature of LRT is its right-of-way flexibility. While streetcars intermingled with other street traffic throughout most of their routes, light rail vehicles (LRVs) typically run along exclusive or semi-exclusive rights-of-way, which permit much faster running speeds. And, unlike a rapid transit line, which runs only on fully grade-separated rights-of-way, such as in tunnels or on elevated structures, an LRT system can make use of several different right-of-way types.

Most commonly, LRVs run within median strips or curb lanes of wide streets or freeways. But systems may also have sections that run in tunnels, on aerial structures, along railroad rights-of-way, down back alleys, along transit-only malls, and occasionally even in streets. The usual practice is to design a line with ■ partial grade separation and some grade crossings. For example, a ground-level light rail line operation has overpasses or underpasses at heavily traveled intersections and ■ limited number of street-level crossings. The design goal is to keep construction costs



down while allowing the cars to achieve a reasonable average speed.

Vehicle technology

Modern LRT systems use articulated vehicles, which are much more cost-effective than shorter rigid cars because they can carry more passengers and are operated by just one person. Consisting of two sections joined at a single truck, or bogie, articulated cars can be much longer yet still negotiate sharp curves. In North America, rigid cars range from 14 to about 20 meters, while articulated vehicles stretch from about 22 to 29 meters.

All LRT systems use dc power at 600–750 volts. The power is typically supplied via overhead line and collected by a pantograph mounted atop the car. To regulate the vehicle's speed, chopper control, used in urban transit since the early 1970s, utilizes solid-state electronics to control the current's flow to the traction motors, providing smooth, jerk-free acceleration and deceleration. This is in contrast to the mechanical cam system of current regulation, which switches current-limiting resistors into and out of the motor circuit.

The chopper control circuitry—similar to that used in modern light dimmers (except, of course, for its power rating)—turns the motor current rapidly on and off, varying the duty cycle (the ratio of on-time to off-time) to achieve the desired acceleration. The development in the 1970s of high-voltage semiconductors (thyristors, especially gate turn-off devices) made the application of variable-voltage dc power for traction propulsion possible.

The dc motors used in all existing systems need frequent maintenance because of the constant wear on their brushes and com-

Defining terms

Block signals: a system for controlling trains in which the track is divided into blocks, and the presence or absence of ■ train in the block is determined by ■ track circuit. The usual practice in light rail transit is simply to display the block signal information on a wayside indicator (traffic light or railroad-type signal).

Grade crossing: the ground-level intersection of roadways, railways, pedestrian walks, or combinations of these.

Grade separation: an intersection employing an underpass or overpass. A fully grade-separated right-of-way has no grade crossings; a partially grade-separated right-of-way has some grade crossings and some grade-separated intersections.

Inverter: ■ device for converting direct current into alternating current.

Median strip: the center strip of a highway, typically used to separate the two directions of traffic. It may be paved or planted, used as a rail bed, or put to many other uses.

Pantograph: ■ vehicle roof-mounted part for collecting current from an overhead conductor to power the vehicle.

Right-of-way: land occupied and used by a road or rail transit line.

Jeffrey Mora
Urban Mass Transportation Administration



A San Diego light rail vehicle is shown at the Hayfront/E Street Station on the 25.6-kilometer line near the Mexican border at San Ysidro. Opened in 1981, this successful system, which uses simple bus-shelter-type stations and a barrier-free proof-of-payment operation, recovers nearly 90 percent of its operating cost from the farebox.

mutators, and must be rewound at intervals of three to five years. The current trend in newer equipment is toward ac propulsion (ACP), which is based on (brushless) ac induction motors and on-board solid-state inverters. ACP greatly reduces maintenance costs while increasing reliability. Also, ac motors need little more than routine lubrication to operate for years, and they are smaller than their dc equivalents.

Of course, the use of ac motors requires that the dc power line be inverted to ac. Inverters for that purpose evolved naturally from dc choppers, and downsized inverters are readily available today.

To decrease speed, almost all rail transit systems use dynamic braking, with the motor slowing down the car by acting as a generator driving a heavy load. Typically that load is made up of resistor grids under the car. However, transit systems with solid-state chopper control can use dynamic braking to boost operating efficiency by feeding the current from the motor back into the power line so other cars in the system can use it.

New light rail cars also provide accessibility for handicapped people in a variety of ways, including on-board lifts, a bridge plate that can be extended to a station platform, and lifts at the stations.

LRT operating practices

The vehicles in modern LRT systems are operated in much the same way as were their streetcar ancestors—a major factor that distinguishes LRT from conventional rail rapid transit. Simplicity is the watchword. An operator, in line-of-sight operation, manually controls the vehicles. In some systems, to increase efficiency, traffic signals are pre-empted by the LRV—that is, when an LRV approaches a grade crossing, sensors in the track detect it and give it a green light, forcing the intersecting automotive traffic to stop.

Simple block signals are used when required on high-speed lines, as in tunnels or in other situations where vision is limited. In LRT, those signals are typically not part of an automatic control system but simply alert the operator to what lies ahead.

Fare collection is a feature that distinguishes modern LRT from both old-fashioned streetcars and rapid transit systems. Requiring no conductors or ticket agents, all new LRT systems use an extremely cost-effective fare collection system that combines off-vehicle ticket purchasing with random on-board proof of payment monitoring.

Simplicity of station design is another element of LRT practice that differentiates it from conventional rapid transit.

Light rail activity in North America includes modernization

of older systems and construction of brand-new ones in 22 major cities [see table].

In 1978, only three years after the initial LRT conference, the Canadian city of Edmonton, Alta., opened North America's first completely new light rail line built to contemporary standards. The 7.2-km line with a 1.6-km downtown subway, including five stations (two in the subway) and 14 articulated railcars, utilized a surface right-of-way partially shared with a railroad.

Los Angeles has North America's newest system. A major segment of the line between Long Beach and downtown Los Angeles opened on July 16, 1990, and a short tunnel in the downtown area will be opened later this year.

The US \$871 million, 34.6-km line will, when completed, have 22 stations, six with park-and-ride facilities. Utilizing off-vehicle fare payment with on-vehicle random verification, the system includes 54 articulated cars built by Nippon Sharyo USA Inc., New York City. Unlike most LRT systems, which use wayside block

The evolution of streetcars in the United States and Europe

Although Europeans have led the way in perfecting modern light rail transit systems, the roots of those systems go back to the United States in the late 1880s, when a pioneering electrical engineer named Frank Julian Sprague built the first practical streetcar system for the city of Richmond, Va. Streetcar systems were very popular with U.S. riders from 1890 until automobile ownership became widespread in the 1920s. Transit ridership rapidly declined after World War II ended.

At that time, government policies favored road building and the dispersal of much of the population to low-density suburbs. This shifting of people from urban centers moved many passengers off the streetcars and into private cars. Simultaneously, the work week was shortened from six days to five, further reducing transit usage.

So just as major capital investments were needed to repair and replace equipment worn out during the wartime ridership boom, private transit companies lost many of their riders and became unprofitable. In most cases, those companies were taken over by public agencies, which were reluctant to invest in system renewal because of enormous pressures to provide more road space for automobiles. Instead, the agencies ripped up or paved over streetcar tracks and replaced the trolley cars with buses, if the previous owners had not already done so.

Meanwhile, in Europe, after the devastation of the war, many cities upgraded their streetcar networks to higher-quality surface rail systems in median strips or similar rights-of-way that were partially separated from competing surface traffic; this upgrading permitted significant speed increases for modest levels of investment. Later, some of these lines were relocated into downtown subways to expand capacity and further increase speed, most notably in Frankfurt, Germany, and Brussels, Belgium. The upgraded lines were called "limited tramways," a term with the same connotation as light rail.

—J.M.

signals in some locations, the one in Los Angeles uses cab signals—a control technique in which indicators in the cab tell the operator whether the track ahead is clear. The system also employs automatic train stop (ATS) to halt the train when conditions warrant if the operator does not reduce speed or stop in response to a restrictive cab signal indication.

The Maryland Mass Transit Administration, based in Baltimore, is building a new 36-km light rail line from the north to the southeast through Baltimore's downtown area. Some right-of-way will be shared with a Conrail railroad line whose freight service will run at night. The \$446 million system, scheduled to open in 1992, will utilize 35 articulated cars built by ABB Trac-tion Inc. (North America's longest cars: 28.9 meters), Lawrenceville, N.J., using an ACP system.

Dallas has the most ambitious new LRT system now being

planned—a total route length of 106 km. Construction on the first 32-km segment started last year. Its cost is expected to be \$630 million, which includes 50 LRVs.

The biggest to date

The largest new U.S. system opened in San Diego in 1981. Much of its right-of-way is a lightly used railroad line that operates at night when the transit system is not running. With the recently opened Bayside extension on the waterfront, it now totals over 56 route kilometers. The fleet includes 71 LRVs, and plans have been announced to purchase another 100 cars for future system extensions.

Although all existing systems serve central business districts, a proposed new system in suburban Washington, D.C., will go nowhere near the downtown area. Instead the proposed line will connect Silver Spring and Bethesda in Maryland's Montgomery County. The line will also link out-lying stations on the city's Metro Red Line.

Elsewhere in the United States, interest in LRT is growing. In automobile-dominated California, four new LRT systems have been built. Important new systems are in the early stages of construction in St. Louis, Mo., and Dallas, and extensions are planned in San Diego, San Francisco, and Sacramento—all in California—and in Portland, Ore., among other activities.

In general, public acceptance of new LRT sys-tems has been excellent. Its great flexibility makes it an attractive transit alternative and complement to other transit modes, including the automobile. Given current events in the Middle East, which have already pushed up the price of gasoline and raised the specter of fuel shortages, it would seem that the future of light rail (and other forms of rail transit) is assured.

To probe further

The most recent comprehensive publication on light rail transit is the proceedings of the fifth National Light Rail Conference, held in San Jose, Calif., May 8-11, 1988. The document, "Light Rail Transit—Special Report No. 221," is available from the Transportation Research Board, National Re-search Council, 2101 Constitution Ave., N.W., Washington, D.C. 20418.

A landmark report that contributed significant-ly to the genesis of light rail in the United States is "Light Rail Transit Systems—A Definition and Evaluation," by Professor Vukan Vuchic of the University of Pennsylvania in Philadelphia. As re-port No. PB 213-447, it is available from the Na-tional Technical Information Service, Springfield, Va. 22161.

About the author

Jeffrey Mora is a research program manager in the U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA) in Washington, D.C. He specializes in technical issues concerning rail systems and vehicles. Previously, he worked in New York City for DeLeuw, Cather and Co., based in Chicago. He earned a master's degree in public administration from the Univer-sity of Pittsburgh and a B.A. in history from the University of Arizona in Tucson. ♦

The views expressed in the article are those of the au-thor and do not necessarily reflect the views of the U.S. Department of Transportation or the Urban Mass Trans- portation Administration.

Light Rail Systems in North America

City	Status*	Comments
Baltimore, Md.	U	The system is scheduled to open in 1992; will use ac propulsion and share some right-of-way with a Conrail branch line
Boston	M	Continuing modernization of the Green Line involves purchase of 100 new low-floor design light rail vehicles
Buffalo, N.Y.	N (1985)	This system is called a light rail rapid transit because its longest segment is in a tunnel
Calgary, Alta., Canada	N (1981)	A short extension to the Northwest Line opened in Sep-tember 1990
Cleveland, Ohio	M	The new Tower City station brings rapid transit and Shaker Heights light rail transit (LRT) services into same platforms
Dallas	U	System is currently planned to have a total length of 106 kilometers; construction has begun
Edmonton, Alta., Canada	N (1978)	This was the first of the modern LRT systems in North America; shares railroad right-of-way
Guadalajara, Mexico	N (1989)	LRT utilizes downtown subway and surface median strip built originally for electric trolley buses
Los Angeles	N (1990)	This newest U.S. system makes use of the old Pacific Electric Railway right-of-way
Mexico City	N	This system is a suburban link to a Metro terminal station
Monterey, Mexico	U	Although completely elevated, this system otherwise uses LRT technology
New Orleans, La.	M	The system uses traditional cars built in the 1920s; in-frastructure renewal is under way
Newark, N.J.	M	Built on an old canal bed, this system was modernized in 1985; carries 15 000 riders daily
Philadelphia	M	The first ac propulsion cars will be delivered in early 1991 for service on suburban Norristown high-speed line
Pittsburgh	M	A new tunnel built under the downtown area in 1985 replaced street track and significantly improved running time
Portland, Ore.	N (1986)	A bond issue approved for local sharing of the West Side Extension (29 km), which will double system size
Sacramento, Calif.	N (1987)	The system shares mixed right-of-way: streets, mall, unused highway segment, and railroad right-of-way
San Diego, Calif.	N (1981)	The largest new U.S. system is primarily run on shared railroad right-of-way
San Francisco	M	A new subway under Market Street completed in 1981 links with older underground and surface sections
San Jose, Calif.	N (1987)	Two extensions from existing terminals are scheduled to open in summer 1991, completing the system
St. Louis, Mo.	U	A 29-km line will link East St. Louis, Ill., with down-town St. Louis and Lambert Airport; construction will begin this year
Toronto	M	A new 2-km Harbourfront Line links Union Station and redeveloped harbor area

* M—Modernized older system. U—Under construction.
N—New system.

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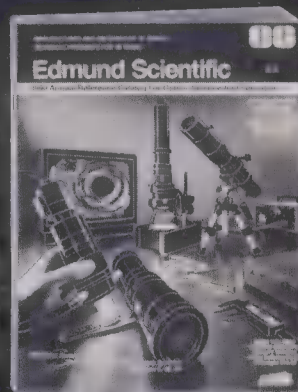
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(continued from p. 19)

agate inside buildings, there have been no widely available propagation models that allow design engineers to predict system performance—and the few that have existed have been very expensive. With the advent of powerful PCs and workstations, however, it is now possible to use off-the-shelf computers to implement intricate propagation simulation software, including the intricacies of wide bandwidth, high data rates, and complex multiple-access techniques.

One such new product is the Simulation of Indoor Radio Channel Impulse-response Modeling (Sircim), developed by Scott Y. Seidel, Theodore S. Rappaport, and others in the mobile and portable radio research group in Virginia Polytechnic Institute's EE department at Blacksburg.

According to Seidel, Sircim is a highly accurate, statistical, UHF multipath indoor radio-propagation simulator that runs on any IBM PC or compatible with a VGA monitor, using TurboPascal version 5.0 or later. It can be used to design, analyze, and engineer in-building radio communication systems.

Sircim simulates time-varying continuous-wave fading signal levels, fading distributions, path-loss values, and wideband impulse responses for a variety of indoor environments. Users may specify the separation between transmitter and receiver, the type of building (such as factory, office building with soft partitions, and so on), topographical information (such as line-of-sight or obstructed radio paths), and channel noise levels.

From these inputs, Sircim generates both wideband and narrowband signal-strength data in the low microwave band (900 megahertz to 4.0 gigahertz). Custom or commercial software can then import Sircim's results to analyze the impact of fading, co-channel and adjacent-channel interference, prediction of outages, bit error rates, and other relevant quantities.

The simulator was developed from extensive measurements collected in 10 different open-plan and partitioned buildings, including office buildings, retail stores, and factories, said Seidel. Propagation characteristics in several more buildings are presently being studied to improve and expand the model.

The price of Sircim is US \$1500 to companies, and \$400 to universities. That price includes access to source code and free user support.

The full capabilities are described in Virginia Tech's technical report MPRG-TR-90-6, "Sircim: A Novel Radio Channel Simulator for Indoor Microcellular Communication System Design," published Sept. 5, 1990. The report is available to anyone by sending a 9-by-12-inch (22.5-by-30-centimeter) self-addressed envelope with \$1.45 postage to Theodore S. Rappaport, the Bradley Department of Electrical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Va. 24061.

Coordinator: Trudy E. Bell

Consultants: Ralph H. Baer and Homer Jensen

(continued from p. 6)

tend to indicate his or her bias.

The report says that "most scientists" now "accept that effects occur," but "it is by no means certain that exposure to fields will pose health risks." In one study, male rats were placed 12 inches [30 centimeters] away from a television that was switched on for 4 hours per day for 35 to 50 days. They experienced reductions in the weight of their testicles and brain chemistry changes—but no health risks? The report says, "Twelve U.S. studies have examined occupational ELF [extremely low frequency] exposure and leukemia. All these show a much increased risk of leukemia"—but no health risks?

Studies have connected 60-Hz radiation with an elevated incidence of suicides and a mechanism has been discovered (depressed levels of serotonin)—but no health risks? The correlation between childhood cancer and ELF radiation found by Nancy Wertheimer has been confirmed in studies in Stockholm, Sweden, and by David Savitz in Denver, Colo. This latter also contained evidence of behavioral and central-nervous system effects—but no health risks?

There are many, many more studies that point to the same conclusion.

Cliff G. Burgess
Hattiesburg, Miss.

Additions

In response to "Light that acts like 'natural bits'" [August, p. 56], several readers pointed out that the theoretical roots of soliton theory go back more than a decade. Akira Hasegawa (F), Distinguished Member of Technical Staff, AT&T Bell Laboratories, Murray Hill, N.J., pointed out that the first paper on the optical soliton was published by himself and Frederick Tappert in *Applied Physics Letters*, Vol. 23, p. 142, 1973. Rolf Landauer (F), IBM Fellow at the Thomas J. Watson Research Center, Yorktown Heights, N.Y., noted that the frequency shift of a laser pulse due to an optical medium's nonlinearity was described by himself and Rudolf J. Joenk in *Physics Letters*, Vol. 24A, p. 228, Feb. 13, 1967.

"To probe further" for the Engineering Software Focus Report [November, p. 94] should have included the second edition of Digital Signal Processing's four-part self-study course: a text titled "Digital Signal Processing" by Alan V. Oppenheim and Ronald W. Schaffer; a study guide by Andrew Sekey; a course reader, "Applications of Digital Signal Processing," edited by Sekey; and an audio cassette tape. Contact: Educational Activities Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; fax, 908-981-1686. —Ed.

Hold on, pardner!

We always expect everything in Texas to be a bit bigger than in any other place. I was surprised, therefore, to read in the item about the radio controlled drying of plaster-

board [November, p. 22] that in Texas plasterboard comes in "4-by-8-inch" sheets.

Out our way, sheets of plasterboard are 4 by 8 feet or 4 by 12 feet. The economics of the matter might be appreciably altered if the study were based on sheets of the size used in the rest of the country.

Frank B. Travis
Bellingham, Wash.

We must have been thinking about microplasterboard.—Ed.

All aboard, 25-Hz users!

The article "The frequency that wouldn't die" [November, p. 120] was noteworthy to us at Amtrak. We have over 1200 miles of 12-kilovolt, single-phase, 25-hertz catenary along the Northeast Corridor and the line from Philadelphia to Harrisburg, Pa.

We would be interested in a users' information exchange group on 25-Hz equipment replacements and common failures. Contact: Director, Electric Traction, National Railroad Passenger Corp., 2000 Market St., Philadelphia, Pa. 19103.

R. Verhelle
Philadelphia

Corrections

On p. 49 of the August issue, beginning with the fifth line of the second column, the paragraph should have concluded "11- or 12-GHz downlink. (Frequencies from 10.7 to 11.7 GHz—referred to as the 11-GHz band—may be used in all International Telecommunication Union regions. Other frequency assignments—referred to as the 12-GHz band—are in ITU Region 2 [North and South America], 11.7–12.1 GHz; and in Regions 1 and 3 [Europe, Mid-East, Africa, Asia, Pacific, and the Orient], 12.5–12.75 GHz. Surface flux density limits, which limit satellite equivalent isotropically radiated power [EIRP], apply in the 10.7–11.7- and 12.5–12.75-GHz bands but not in the 11.7–12.1-GHz band. Generically, this combination of usages has been referred to as 14/11–14/12 GHz.)" The author elected to use the definition of EIRP given in the *IEEE Standard Dictionary of Electrical and Electronics Terms*, which defines "effective" and "equivalent" isotropically radiated power as synonymous. Some reviewers disagreed, observing that "effective" should be reserved for the case of a dipole reference, and the correct term would then be "effective radiated power."

On p. 60 of the November issue, in the table on "Affordable Analog Design," the Saber software package should have been listed with a library of 3400 parts.

On p. 74 of the issue, Integrated Engineering Software's electromagnetics software program Coulomb should have been listed as 3-D only, with price options ranging from US \$6650 to \$17 500.

On p. 98 of the issue, Technical Systems Integrators Inc.'s telephone number should have been 407-380-5181; the contact person should have been Mary Alejandro.

On p. 59 of the December issue, two company names were misspelled. The correct names are GEC Plessey Telecommunications and Northern Telecom. —Ed.



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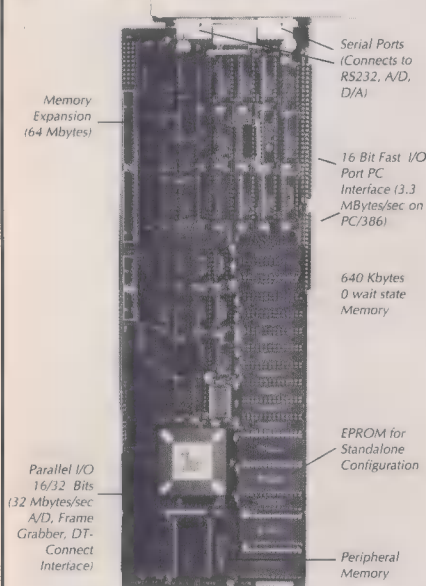
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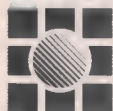
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Circle No. 10

Plastic-packaged ICs in military equipment

Long vehemently opposed to plastic packaging for integrated circuits, the U.S. military is reconsidering its position. Rome Laboratory (formerly Rome Air Development Center), New York, is in the final stages of revising MIL-I-38535, the specifications for IC manufacturing, to allow the use of plastic-encapsulated chips from qualified sources in military equipment. Meanwhile, in Fort Monmouth, N.J., the U.S. Army Electronics Laboratory Command is just finishing a document, "Microcircuit Applications Guidebook," that suggests that equipment designers not automatically specify hermetically sealed ceramic or metal packages, but instead consider plastic packages. Both documents will be circulated to manufacturers, users, and Government agencies for comments, and final Government approval is expected by the end of the year.

The military's suspicion of plastic packaging was well-founded. In the late 1960s, when it was introduced, the services found the porous nature of the material let in corrosive moisture, and chips quickly failed. Corrosive chemicals in the plastic itself attacked chips. And the stresses of thermal cycling broke wire bonds and admitted moisture along the leads.

Today, however, plastic IC reliability is much improved, and statistics are available to prove it. A group of French engineers working at Thomson-CSF and Texas Instruments France SA, under French Army sponsorship, found that the reliability of the best plastic-packaged ICs ranges from

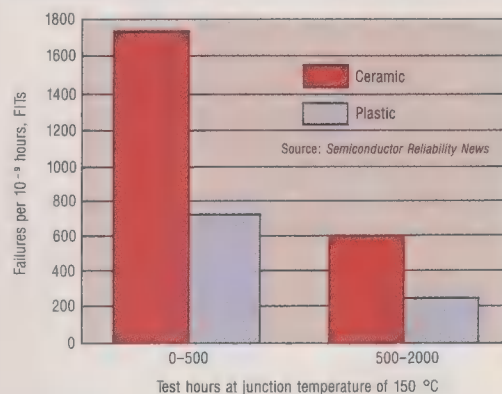
have invested in complex finite-element analyses of the thermomechanical behavior of plastic packages and have modified their designs and processes on the basis of their findings. For example, their engineers choose the plastic encapsulant so that it is fairly compliant to thermal and mechanical stresses. They adjust bond-wire clearance and length and metal-path width and shape to reduce stresses imposed on them. They have also learned how to passivate the chip surface to minimize attack by moisture and other corrosives. With such measures, FITs of 10 to 50 are routinely attained.

The military's reconsideration is based on economics: plastic packages cost a small fraction of ceramic ones—a few cents versus a few dollars. This is because chips are plastic encapsulated by fast, economical injection molding, whereas ceramic packs are sealed by a slower, more difficult glass-bonding process—and the ceramic material itself is expensive. With newly reduced budgets, the armed services want to reduce the costs of new equipment, which is increasingly electronic and holds an ever greater number of ICs. A reduction in package costs means a substantial savings in overall equipment costs, provided that reliability testing is kept to a minimum.

Military equipment producers also want to exploit the advantages of surface-mounted packages, which accommodate larger chips and more pins per package than dual in-line packages (DIPs) and thus yield more compact electronics. Ceramic surface-mounted packages are even more costly than ceramic DIPs, while there is little difference in cost between plastic surface-mounted packages and DIPs. Only when the number of pins is very large—about 150 or more—does ceramic surface-mounted packaging become cost-effective.

Military reliability engineers caution, however, that the cost advantage of plastic packaging is lost if the ICs have to be individually tested to rigid military specifications, a labor-intensive procedure. Instead, they envision a collaboration between IC manufacturers and military customers. Manufacturers will be evaluated on their design quality, manufacturing skill, industry leadership, and customer satisfaction, for example. As long as they meet high standards in these respects, their plastic ICs will be accepted for military applications with minimal testing.

Stimulating the military's interest in plastic packaging is the automotive industry's favorable experience. The industry consumes plastic ICs at the amazing rate of 2.7 million per day. Automotive manufacturers were initially attracted by the low cost of plastic, but they discovered that plastic-encapsulated chips were reliable, too—a welcome attribute when chips are proliferating in cars and trucks and competition is forcing manufacturers to



In controlled environments, ICs in plastic may be more reliable (Signetics data).

1 to 10 FITs (device failures in 10 billion hours). This is a far cry from the 2000 FITs measured on the same products a couple of years ago, and approaches the reliability of ceramic packages. Plastic ICs are still not as resistant as ceramic-packaged ICs to thermal cycling, but they are improving fast. Plastic-packaged units show the poorest reliability in applications with long off-times because moisture infiltrates.

These new low FIT values do not apply to all IC products or manufacturers, to be sure. They do apply to manufacturers who

offer warranties of five years or more. Indeed, auto industry leaders predict that the field defect rate will reach the low level of 0.1 cumulative failure in five years or 50 000 miles (80 000 kilometers) by the late 1990s with continued process and design improvements. Military customers are encouraged that automotive environments are as severe as those of much ground-based military equipment.

Patrick Layden, who is overseeing the preparation of the Department of Defense's "Microcircuit Applications Guidebook" at Fort Monmouth, told *IEEE Spectrum* that the document's purpose is to encourage a more commonsense approach. "When a circuit board will be used in a controlled environment, it doesn't make sense to go to ceramic packages for the ICs," he said.

The DOD guidebook therefore categorizes service environments according to severity and advises readers on the appropriate choice of package and qualification testing for ICs in each environment. It also categorizes applications according to how critical reliability is to them. Readers will be expected to exercise judgment in writing specifications instead of blindly calling for MIL-SPEC devices.

Evidence is growing that plastic may actually be superior to ceramic packaging in air-conditioned, low-humidity environments. Signetics Corp., Sunnyvale, Calif., reports IC package failure rates more than twice as high for ceramic as for plastic in continuous-operation tests in dry surroundings. The reason is that moisture is driven out of an epoxy plastic package but is trapped inside a ceramic package by the hermetic seal.

One obstacle to the wider acceptance of plastic is that ICs for U.S. military equipment must be made in the United States—and almost all plastic-packaged ICs are made overseas. U.S. manufacturers may be unwilling to set up onshore factories just for a relatively limited (and, in plastic, low-cost) military market. But a movement is under way to amend the rules to permit off-shore assembly facilities to qualify as sources for the U.S. military. The newsletter *Semiconductor Reliability News* reports that people in the industry believe that this could happen before year-end.

Another inhibiting factor is the military's reluctance to add new items to its list of acceptable ICs—a plastic-packaged IC for every ceramic-packaged IC on the list. It costs US \$20 000 per year or more to track the inventory of each item. The savings from using plastic packaging will more than compensate, however.

Circuit-board assembly procedures may also have to be changed to adapt to the limitations of plastic. The Thomson-CSF/TF France researchers found that wave soldering, in which IC package pins are joined to a circuit board by a wave of molten solder, can cause a thermal shock inside plastic packages, separating the plastic from the chip, which may then become contaminated. The gentler method of vapor soldering, in which vaporized solder condenses and solidifies at the pins, avoids the problem entirely.

Coordinator: George F. Watson
Consultants: John R. Devaney, Hi-Rel Laboratories Inc.; Robert Thomas, Rome Air Development Center

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Circle No. 27

Cutback in funding troubles researchers

U.S. engineers troubled by declining budgets and recessionary times may be interested in how these factors are affecting an allied group, U.S. research scientists. The researchers seem just as troubled.

Overwhelmingly, they feel that diminished Federal funding for research has slowed and even altered how they pursue answers to scientific problems, according to ■ report prepared last month for the American Association for the Advancement of Science (AAAS), Washington, D.C. The report, based on an informal survey of research scientists at 50 U.S. universities, "raises serious questions about the very future of science in the United States," said the report's author, physicist Leon M. Lederman, Nobel laureate and president-elect of the AAAS.

The responses of some 250 scientists to the inquiry, conducted by Lederman last summer and fall, indicate that:

- University researchers are now less likely to pursue high-risk scientific inquiries with potentially high payoffs. Instead, they're "sticking to research in which an end product is assured, or worse, working in fields that they believe are favored by funding agency officials."

■ Ideas generated in academic laboratories are often carried to fruition in foreign labs that are better equipped; in comparison, many U.S. facilities are stocked with aging and inadequate equipment, with little or no funding for repairs and updating.

- Academic scientists are cutting back on the number of students they are training, and students now in laboratories are opting out of research careers.

- Scientists at even the best-funded universities spend an inordinate and increasing proportion of their time seeking funding, rather than conducting research.

Lederman called for a doubling of Federal funds for academic research, as well as the development of innovative financing approaches to augment these funds, and the establishment of a commission to investigate such options. He noted that Federal funding for both basic and applied scientific research in universities in 1990 was only slightly greater than it was in 1968 after correcting for inflation.

The survey, Lederman's informal attempt to "take the pulse of America's scientific community," included researchers at the 30 universities receiving the greatest amount of Federal funds for research, as well as 20 less research-intensive institutions.

Lederman was particularly interested in the comments of those considered "win-

ners" in the game of academic science—the people with successful careers in the best-funded disciplines at prestigious institutions. "If these researchers report problems, it could be assumed that the great body of American scientists could only be worse off," said the report's executive summary.

Copies of the report are available by writing to: *The American Association for the Advancement of Science, Directorate for Science and Policy Programs, 1333 H St., N.W., Washington, D.C. 20005.*

Civilian science and public policy

The U.S. government's role in civilian, as opposed to military, technologies is being examined by a joint panel of the U.S. National Academies of Science and Engineering and the Institute of Medicine. It will study the effectiveness of Federal government programs in fostering R&D in civilian technologies, and in recommending actions to bolster the United States' competitiveness in world markets.

Public-private R&D ventures, such as Sematech, the industry consortium in Austin, Texas, that is developing advanced methods for fabricating ICs, will come under review, ■ will collaborative R&D efforts overseas, and government policies

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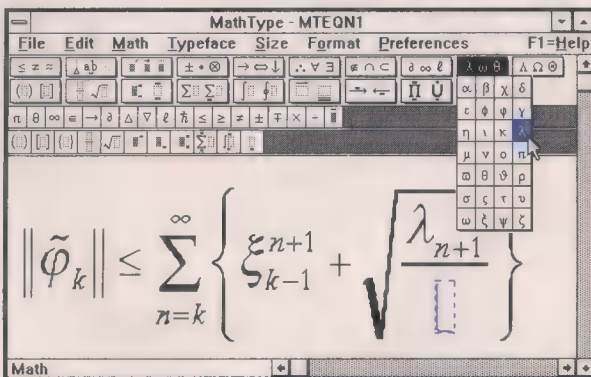


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there that promote technology development; the feasibility of a civilian counterpart to the U.S. Defense Advanced Research Projects Agency; and the role of the national laboratories and other Federal agencies in technology transfer.

Harold Brown, chair of the Foreign Policy Institute of the Johns Hopkins School of Advanced International Studies, Baltimore, Md., and a former Secretary of Defense, chairs the panel. A report is expected in the fall of this year.

Test for young talent

If you know any young people who in your opinion might do well in a science career, consider having them take the National Engineering Aptitude Search (NEAS) examination. Sponsored by the nonprofit Junior Engineering Technical Society, Alexandria, Va., the three-hour examination for high-school students tests mathematical understanding, science reading and comprehension, and problem solving ability. It helps students determine their aptitude for engineering, math, and science before entering college.

The exam is offered in two versions—one for 9th and 10th grade students, the other for 11th and 12th graders. Taking the test in the lower grades gives students an idea of their strengths and weaknesses—knowledge they can then use as the basis for choosing courses. In the higher grades, the exam gives students a means of evaluating their mathematical and scientific

readiness for college.

The exam is prepared and administered by the American College Testing (ACT) program. It is given throughout the year at more than 200 cities throughout the United States. The test fee is \$15. Contact: ACT, NEAS Information, Box 168, Iowa City, Iowa 52243; 319-337-1133.

Engineering's Nobel

Nominations are being sought for candidates to receive engineering's highest achievement award, the Charles Stark Draper Prize. First presented in 1989, the biennial award honors those whose engineering innovations, along with the transfer to practice of those innovations, "have contributed to human welfare and freedom." Jack S. Kilby and Robert N. Noyce received the initial prize jointly for their independent co-invention of the integrated circuit.

The prize, which includes a gold medal and US \$375 000, is awarded by the National Academy of Engineering, Washington, D.C. It is named for Charles "Doc" Draper, the father of modern inertial navigation systems, and is endowed by the Charles Stark Draper Laboratory Inc., Cambridge, Mass.

Said a participant in the first award ceremony, the prize's purpose is to "focus world attention on the important contributions of engineers in the same way that the Nobel Prize now focuses attention on the accomplishments of scientists." The

prize's next recipient will be announced in October. Candidates are being sought through members and associates of academies and societies of engineering worldwide. Contact: Draper Prize, National Academy of Engineering, 2101 Constitution Ave., N.W., Washington, D.C. 20418.

Honest writing

Ethical violations creeping into engineering reports or papers could eventually sully the author's professional reputation, according to Herb Michaelson, author of the third (1990) edition of *How To Write and Publish Engineering Papers and Reports*. He pointed out that such indiscretions can take various forms in technical documents: the sins of omission, the carelessness of ambiguity, the lack of proper acknowledgment, the fudging of data, and the credit-grabbing of plagiarism.

Examples of these ethical misdeeds, unintentional or otherwise, are included in one of the four new chapters Michaelson wrote for this edition of his book. The other new chapters deal with collaboration among networked coauthors, persuasiveness in internal technical proposals, and the basics of page layout and design for an engineer approaching desktop publishing. The 240-page paperback costs US \$19.95. Contact: Oryx Press, 4041 N. Central Ave., Suite 700, Phoenix, Ariz. 85012-3399; 800-279-6799; fax: 800-279-4663.

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Beware the vandalware

Vandalware—computer programs that attack software, individual computers, or networks—continues to menace. Most vandalware now in existence takes one of three forms: the Trojan horse, the virus, or the worm.

A Trojan horse is a parasitic code segment embedded in a program, so called because it allows an unauthorized person to take control of the program. It is planned vandalware: its creators know who the victims will be and what effects the miscreant code will have.

A virus, a close cousin of the Trojan horse, is a program that attaches itself to other programs. It is called a virus because it multiplies by infecting healthy programs. It is passed from computer to computer as users run infected programs on healthy computers.

Viruses are self-limiting in that they only infect existing programs with certain attributes. Once a virus is attached to every executable program with those attributes in the infected computer, it can no longer procreate. Viruses are random vandalware: their creators know what the effects will be but not the victims. Fortunately, they are usually benign unless activated by unusual activity in the operating systems, typically a date like Friday the 13th or April 1 (April Fools' Day).

A worm is a program that reproduces itself. It is called a worm because it reproduces without a partner. Unlike a virus, it does not infect other programs. It passes from computer to network to computer because it makes copies of itself on available disk drives.

Worms are also random vandalware: their creators know what the effects will be but don't know the victims. Unfortunately, worms are never benign, because they continue to reproduce, reducing the amount of available disk and memory. Typically a worm will reproduce until it fills all available disk space.

Computer users can protect themselves from vandalware if they take reasonable precautions. They should buy software from reputable vendors; they should demand reasonably tight network security; and they should use an antivirus software package.

Most antivirus packages contain at least three programs: a scanner that identifies infected programs, a clean-up program that removes the offending code from infected programs, and a vaccine program that detects and blocks the action of viruses.

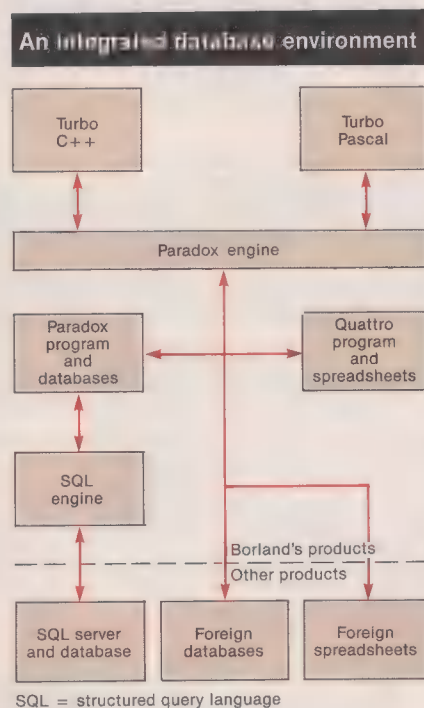
Since over 200 variations of 100 different viruses and worms have been identified, the antivirus package should be purchased from a vendor who updates it frequently. Current shareware antivirus programs for both IBM-compatible PCs and the Macintosh can be downloaded from McAfee Associates Bulletin Board at 408-988-4004. To learn more about viruses, read *Rogue Programs* (Van Nostrand Rein-

hold, 1990) by Lance J. Hoffman, or contact the Computer Virus Industry Association, 4423 Cheeney St., Santa Clara, Calif. 95054; 408-727-4559, or circle 100.

Building integrated programs

Although integrated programs, linking several dissimilar processes with a common interface and file format, received a lot of press in the 1980s, few achieved significant market share. But now developers are creating them by linking existing stand-alone programs the user already knows and uses. However, the developers must still solve the interface and linkage problems with innovative programming techniques.

One solution is to tightly link stand-alone programs under a graphical operating environment with well-defined user interface and interprocess communications standards. Windows and Presentation Manager on IBM-compatible personal computers, System 7 on the Macintosh, and OS/Motif on workstations all offer satisfactory solutions.



This approach is being used by most software vendors for future product development. Developers can link a program to another program running under the same environment without significant intervention from the developers of the latter as long as both follow the programming conventions defined by the operating environment.

Using a graphical operating environment with strong interprocess communications has two drawbacks. It imposes heavy overhead requirements, often a 25-50 percent speed reduction. And significant modifications must be made to existing programs before they can take advantage

of the interface or communications standards. Moving to a graphical operating environment typically takes many man-years of rework.

A second solution is to loosely link two or more existing stand-alone programs under a traditional operating environment like DOS or Unix. The illustration shows Borland International's approach to integrated software running under DOS. In this scheme, a structured query language (SQL) database engine links various SQL servers, which preprocess requests from clients with Paradox, the company's database program. Utility programs and internal hooks link Paradox and Quattro, a spreadsheet program by the same company. Also, the Paradox Engine links Paradox and Quattro with its programming languages. In this and similar schemes, developers need only make modifications to the interfaces to eliminate contradictions and to create utility programs that implement interprocess communications.

This approach is a good solution for current products. The programs require only minor modifications to create the linkage between the programs. Also, interprocess communication can be accomplished by utility programs called from the stand-alone programs.

Linking existing programs under their current operating environment has two drawbacks of its own. The developers of the stand-alone programs must cooperate to develop the links between them. Also, traditional operating environments like DOS and Finder are less flexible and less powerful than modern operating environments such as OS/2 and System 7.

About software copyrights

From a legal standpoint, software can be roughly broken into two categories: public-domain or copyrighted code. Public-domain software may be used by any programmer without restriction. Copyrighted software can be used by other programmers only with the copyright holder's permission.

Public-domain software cannot usually be copyrighted at a later date, so programmers should copyright all software they do not want to donate to the programming public. Form TX, the form for copyrighting software, can be obtained from the U. S. Copyright Office Hot Line at 202-707-9100. The fee for filing the form is only US \$20.

The recent court decision invalidating Ashton-Tate's copyrights on its older database products emphasizes the importance of properly copyrighting software. Additional information can be obtained from the U. S. Copyright Office, 101 Independence Ave., S. E., Washington, D.C. 20559; 202-479-0700, or circle 101.

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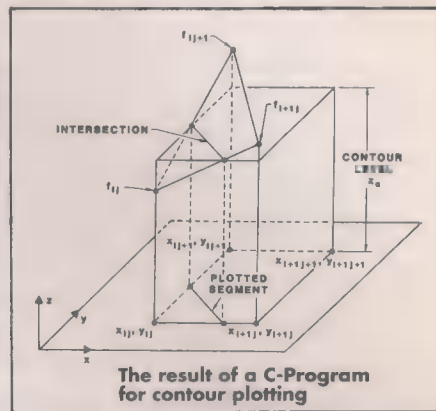
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Please send resumes and names, addresses and phone numbers of four references to the Hitachi Chair Recruitment Committee, School of Electrical Engineering and Computer Science, University of Oklahoma, 202 W. Boyd, Norman, OK 73019. Screening will begin April 15, 1991, and will continue until the position is filled.

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CALENDAR

(continued from p. 18B)

20723-6099; Baltimore, 301-792-5000, ext. 8057; Washington, 301-953-5000, ext. 8057.

Custom Integrated Circuits Conference (ED); May 12-15; Town and Country Hotel, San Diego, Calif.; Laura Morihara, Convention Coordinating, 298 Ohina Place, Kihei, Maui, Hawaii 96753; or Roberta Kaspar, 1597 Ridge Rd. W., Suite 101C, Rochester, N.Y. 14615; 716-865-7164; fax, 716-865-2639.

Ideas in Science and Electronics Symposium and Exposition (IEEE Albuquerque et al.); May 14-16; Albuquerque Convention Center, Albuquerque, N.M.; Dave Smoker Communications, 218 Manzano, N.E., Albuquerque, N.M. 87108; 505-266-7292; or Charles E. Christmann, c/o ISE Inc., 8100 Mountain Road N.E., Suite 109, Albuquerque, N.M. 87110; 505-262-1023.

IEEE Instrumentation and Measurement Technology Conference (IMTC); May 14-16; Omni Hotel at CNN Center, Atlanta, Ga.; Robert Myers, 3685 Motor Ave., Suite 240, Los Angeles, Calif. 90034; 213-287-1463; fax, 213-287-1851.

Vehicular Technology Conference (VT et al.); May 19-22; Sheridan West Port Inns, Maryland Heights, Mo.; Jay Underdown, 58 Judy Dr., St. Charles, Mo. 63301; 314-946-9980 (O); 314-723-4200 (H).

National Aerospace and Electronics Conference-NAECON '91 (AES et al.); May 20-24; Dayton Convention Center, Dayton, Ohio; Sue Brown, ASD/ENES, Wright-Patterson AFB, Ohio 45433-6503; 513-255-6281.

Annual IEEE/ASME Joint Railroad Conference (IEEE et al.); May 21-23; Sheraton Westport Inn, 191 Westport Plaza, St. Louis, Mo. 63146; Robert B. Fisher, Land Transportation Division, Southeastern Pennsylvania Transportation Authority, 5800 Bustleton Ave., Philadelphia, Pa. 19149; 215-580-4888.

International Symposium on VLSI Technology, Systems, and Applications (ED); May 22-24; Lai Lai Sheraton Hotel, Taipei, Taiwan; Alice Chiang, 617-981-0711.

Mediterranean Electrotechnical Conference (Region 8); May 22-24; Ljubljana, Yugoslavia; Bal-domir Zajc, Fakulteta za Elektrotehniko, Trzaska 25, 61000 Ljubljana, Yugoslavia.

45th Annual Symposium on Frequency Control (UFFC); May 29-31; Marriott Los Angeles Airport, Los Angeles, Calif.; Dr. Raymond L. Filler, U.S. Army Electronics and Technical Devices Laboratory, SLCET-EQ, Fort Monmouth, N.J. 07703; 908-544-2467.

JUNE

Fourth International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems (COMP et al.); June 2-5; Waiohai Hotel, Kauai, Hawaii; Moonis Ali, University of Tennessee Space Institute, MS15, B.H. Goethert Parkway, Tullahoma, Tenn. 37388; 615-455-0631, ext. 236; fax, 615-454-2354.

(continued on p. 66F)

Research Scientist - Technology Transfer

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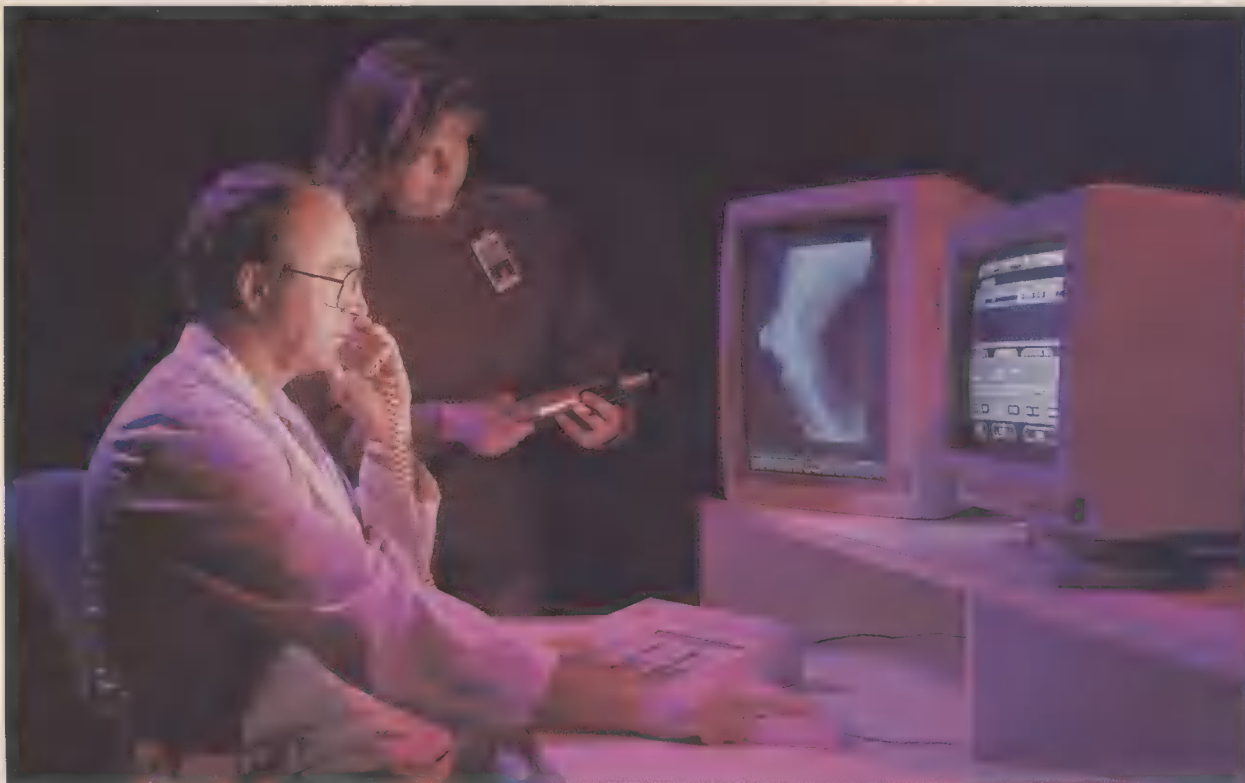
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(continued from p. 66D)

1991 International Conference on Consumer Electronics (IEEE et al.); June 5-7; Educational Session, June 4; Westin Hotel O'Hare, Rosemont, Ill.; Diane D. Williams, 67 Raspberry Patch Dr., Rochester, N.Y. 14612; 776-865-2938.

IEEE Pulp and Paper Industry Conference (IA); June 3-7; Hotel des Gouverneurs Le Grand, Montreal; Michel Riverin, Relcon Inc., 0403 Clement St., Montreal, Que., Canada; 514-595-5999; fax, 514-595-5680.

Intensive Course on Electrical Contacts (IEEE/CHMT); June 3-7; Radisson Plaza Raleigh, Raleigh, N.C.; IEEE Holm Conference Registrar, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-562-3863; fax, 908-562-1571.

International Microwave Symposium-MTT '91 (MTT); June 11-13; Hynes Convention Center, Boston; Peter Staecker, MA-COM, M/S 704, 52 South Ave., Burlington, Mass. 01803; 617-272-3000, ext. 1602.

Device Research Conference (ED); June 16-19; University of Colorado, Boulder; Larry Colgren, University of California, Department of Electrical Engineering and Computer Engineering, Santa Barbara, Calif. 93106; 805-893-4486.

Eighth IEEE Pulsed Power Conference (ED); June 17-19; Sheraton Island Harbor Hotel, San Diego, Calif.; Roger White, Maxwell Laboratories Inc., 8888 Balboa Ave., San Diego, Calif. 92123; 619-576-7884.

University/Government/Industry Conference (ED); June 18-20; Melbourne Holiday Inn, Oceanside, Fla.; Thomas Sanders, 407-768-8000, Florida Institute of Technology, 150 W. University Blvd., Melbourne, Fla. 32901; 407-768-8000, ext. 8769/8763.

Joint Magnetism and Magnetic Materials-Intermag Conference (MAG); June 18-21; Pittsburgh Hilton, Pittsburgh; Diane Suiters, Conference Coordinator, 655 15th St., N.W., Suite 300, Washington, D.C. 20005; 202-639-5088; fax, 202-347-6109.

SSIT Interdisciplinary Conference (SSIT); June 21-22; Ryerson Polytechnical Institute, Toronto, Ontario; Diane Falkner, Program Director Conferences, Ryerson Polytechnical Institute, 350 Victoria St., Toronto, Ont. M5B 2K3, Canada; 416-979-5184; fax, 416-979-5148.

International Conference on Communications (COMP); June 23-26; Denver Technical Center, Hyatt and Sheraton, Denver, Colo.; Russell Johnson, Western-Telecommunications Inc., 4643 S. Ulster St., Suite 400, Denver, Colo. 80237; 303-721-5650.

Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting (AP); June 23-27; University of Western Ontario, London, Ont., Canada; A. R. Webster, Faculty of Engineering Science, University of Western Ontario, London, Ont. N6A 5B9, Canada; 519-679-6294.

International Symposium on Information Theory (IT); June 23-28; Budapest Conference Center, Budapest, Hungary; Anthony Ephre-

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mides, Department of Electrical Engineering, University of Maryland, College Park, Md. 20742; 301-405-3641.

Power Electronics Specialist Conference- PESC '91 (PEL); June 24-28; Massachusetts Institute of Technology (MIT), Cambridge; Martin Schlecht, MIT, Room 39-553, Cambridge, Mass. 02139; 617-253-3407.

Transducers '91: International Solid-State Sensors and Actuators Conference (ED); June 24-28; Hyatt Regency Hotel, San Francisco; Richard S. Muller, 497 Cory Hall, Berkeley Sensor and Actuators Center, University of California at Berkeley, Berkeley, Calif. 94720; 415-642-0614.

American Control Conference-ACC '91 (CS); June 26-28; Boston; Timothy Johnson, General Electric Co., Research and Development, KWD 217, Box 8, Schenectady, N.Y. 12345; 518-387-5096.

JULY

28th IEEE Nuclear and Space Radiation Effects Conference (IEEE Nuclear and Plasma Sciences Society); July 15-19; Town and Country Hotel, San Diego, Calif.; James R. Schwank, Sandia National Laboratories, Division 2144, Box 5800, Albuquerque, N.M. 87185; 505-846-8485.

AUGUST

International Symposium on Electromagnetic Compatibility-EMC '91 (EMC et al.); Aug. 13-15; Hyatt Cherry Hill, Cherry Hill, N.J.; Henry W. Ott, 45 Baker Rd., Livingston, N.J. 07039; 201-386-6660.

SEPTEMBER

Bipolar Circuits and Technology Meeting (ED); Sept. 9-10; Minneapolis Marriott Hotel, Minneapolis, Minn.; John Shier, 2401 E. 86th St., Bloomington, Minn. 55425; 612-851-5228.

Petroleum and Chemical Industry Technical Conference (IA); Sept. 9-11; Royal York, Toronto; Barry Wiseman, Reliance Electric Co., 5220 Creekbank Rd., Mississauga, Ont., Canada L3W 1X1; 416-625-8112.

Third International Conference on Microstructures in Biological Research (ED); Sept. 9-12; Fort McGruder Inn and Conference Center, Williamsburg, Va.; Martin Peckerar, Naval Research Laboratory, 4555 Overlook Ave., Washington, D.C. 20375-5000; 202-767-3150.

Seventh Multidimensional Signal Processing Workshop (SP); Sept. 23-25; Whiteface Inn, Lake Placid, N.Y.; John Woods, Computer and Systems Engineering, Rensselaer Polytechnic Institute, Troy, N.Y. 12181; 518-276-6079.

18th International Conference on Computers in Cardiology (COMP et al.); Sept. 23-26; Venice, Italy; Corso Stati Uniti 4, 35020 Padova, Italy; (39+49) 829 5702.

International Symposium on Gallium Arsenide and Related Compounds (ED); Sept. 23-26; Seattle, Wash.; L. Ralph Dawson, 505-846-3451.

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RECENT BOOKS

(Continued from p. 13)

Origins: The Lives and Worlds of Modern Cosmologists. Lightman, Alan, and Brawer, Roberta, Harvard University Press, Cambridge, Mass., 1990, 563 pp., \$29.95.

An Architecture for Combinator Graph Reduction. Koopman, Philip John Jr., Academic Press, San Diego, Calif., 1990, 155 pp., \$94.50.

Indium Phosphide: Crystal Growth and Characterization; Semiconductors and Semimetals. Eds. Willardson, R.K., and Beer, Albert C., Academic Press, San Diego, Calif., 1990, 394 pp., \$94.50

Dictionary of Artificial Intelligence. Mercadal, Dennis, Van Nostrand Reinhold, Florence, Ky., 1990, 334 pp., \$29.95.

Discrete Cosine Transform. Rao, K.R., and Yip, P., Academic Press, San Diego, Calif., 1990, 490 pp., \$69.95.

The Maplin Electronics Circuits Handbook. Tooley, Michael, Butterworth Heinemann, Stoneham, Mass., 1990, 288 pp., \$27.95.

Assembler for COBOL Programmers: MVS VM. Murphy, Hank, McGraw-Hill, New York, 1990, 496 pp., \$39.95.

Computers at Risk: Safe Computing in the Information Age. Ed. National Research Council et al., National Academy Press, Washington, D.C., 1991, 303 pp., \$19.95.

Computer and Communication Systems Performance Modelling. Ed. Hoare, C.A.R., Prentice-Hall, New York, 1990, 245 pp., \$41.

Advances in Computers-Vol.31. Ed. Yovits, Marshall C., Academic Press, San Diego, Calif., 1990, 405 pp., \$69.95.

Power Electronics and Variable Speed Drives. Evans, P. D., et al., Institution of Electrical Engineers, London, 1990, 561 pp., \$130.

Factory 2001: Integrating Information and Material Flow. Wilson, D. R., et al., Institution of Electrical Engineers, London, 1990, 218 pp., \$74.

Optical Scattering: Measurement and Analysis. Ed. Stover, John C., Fischer, Robert E., and Smith, Warren J., McGraw-Hill, New York, 1990, 238 pp., \$44.95.

Modern Optical Engineering: The Design of Optical Systems-2nd Edition. Smith, Warren J., McGraw-Hill, New York, 1990, 524 pp., \$59.50.

Field Theories in Condensed Matter Physics: A Workshop. Ed. Tسانovic, Zlatko, Addison-Wesley, Redwood City, Calif., 1990, 216 pp., \$45.25.

Patents, Getting One... A Cost-Cutting Primer for Inventors. Paterson, Stuart, Academy Books, Rutland, Vt., 1990, 472 pp., \$43.95.

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The Electric 500

Auto racing, a time-honored means of testing innovative automotive developments, will be used next spring to foster the development of electrically powered vehicles. So if you are in Phoenix, Ariz., next April 5-7, you might consider attending the races and exhibits at the First Annual Solar & Electric 500. Better yet, if you are actually working on a high-performance electric car, you still have time to enter the competition, to be fought out on the oval track at the Phoenix International Raceway.

Organized by the Solar and Electric Racing Association (SERA), which was formed last year in Phoenix, the 500 has two competition classes—vehicles powered by solar energy and those running on stored electricity. Solar-powered vehicles in the

147 mph (245 kph) from a standing start. Only the hottest of conventional cars powered by internal-combustion engines can rival that speed. Visitors will also be allowed to take some of the vehicles out for a drive.

Deadline for entering a vehicle in the competition is March 4. Tickets for the 500, at US \$7-\$10 each, are available from SERA or Ticketmaster. Children under 12 are admitted free. *Contact: Ernest Holden, Solar and Electric Racing Association, 11811 N. Tatum, Suite 3031, Phoenix, Ariz. 85028; 602-953-6672.*

SOFTWARE

Simulating IC fab steps

The manufacturing processes used to fabricate ICs can now be simulated on the

IBM PC and compatibles with software from the California firm of Technology Modeling Associates Inc. The PC simulation package has essentially the same capabilities as software provided by the company for larger workstations and mainframe computers, said marketing vice president Roy Jewell. Technology Modeling makes the TMA Suprem-3, a one-dimensional process simulator used in more than 130 organizations in the semiconductor industry.

The software simulates standard IC processing steps, including oxidation of silicon, polysilicon, and silicon nitride; diffusion of impurities; ion implantation; deposition; and etching. The new software operates on all 286-, 386-, and 486-based personal computers. *Contact: Roy Jewell, Technology Modeling Associates Inc., Third Floor, 300 Hamilton Ave., Palo Alto, Calif. 94301; 415-327-6300; fax, 415-325-2960; or circle 104.*

PC animation

An expensive workstation is no longer essential if you need to animate graphics. Your IBM PC or compatible also can be made to quickly sequence through and display a series of video images.

Micro-Movies is a set of graphics utilities that can capture VGA or EGA graphic images and play them back. The developer, Eclectic Systems, claims that an 80286 running at 12 megahertz can display 15 or 20 frames per second. The user must be able to create each frame and then invoke Micro-Movies' capture utility. This utility can run as a TSR (terminate and stay resident) so that it can be activated by any commercial graphics package. It can also be called by user-written software. Fortran,

C, Pascal, and Quickbasic are supported. The data are stored in a compressed format, enabling 150 frames to be stored on a high-density disk.

The tool's playback utility reads the entire sequence into memory (up to 4 megabytes of expanded memory are supported) and displays each frame on the monitor. Playback speed can be changed, and the sequence run backward or stopped at any time. A "script" facility lets you automate a playback sequence for presentations or educational purposes. The playback utility is not copy protected, so that users are free to distribute any presentation to associates or customers via disk or modem.

Micro-Movies is available for \$200 directly from the developer. *Contact: Eclectic Systems, 8106 St. David Court, Springfield, Va. 22153; 703-440-0064, or circle 106.*

Easier electromagnetic analysis

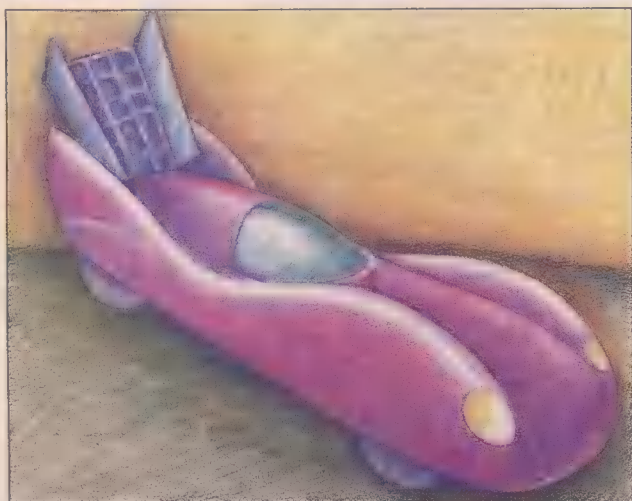
Engineers who design or analyze magnetic equipment or components might consider using Amperes, an interactive computer tool introduced by Integrated Engineering Software. Amperes has a wide range of applications, including modeling magnetizing fixtures and permanent-magnet assemblies; designing of circuit breakers, transformers, solenoids, and reclosers; and designing electric motor and magnetic circuits. The program solves linear or nonlinear, three-dimensional, static or quasi-static magnetic field problems.

The minimum configuration for Amperes is an 80386 microprocessor and 80387 math coprocessor with 4M bytes of random-access memory and a mouse. The 386SX model is not supported, and the developers recommend a Weitek coprocessor and a large hard drive. Using a 25-megahertz 386 and a Weitek, it takes five hours to solve a problem with 3300 unknowns. This drops to two hours with a 486/Weitek configuration. Problems of that size also require about 150 megabytes of hard-disk space; 6144 unknowns require 512 megabytes.

Data entry is mouse and menu driven. The user enters the problem's geometry, material properties, currents, conductors, and, because Amperes uses the boundary-element method, the boundary-element discretization. No finite-element mesh is required.

Amperes can solve for several aspects of the electromagnetic problem, including scalar and vector field distributions, the lumped inductance matrix, mutual and self-inductances, and torque about any line. The user can also choose among several display formats. Potential and magnetic field values are provided at any desired location and can be displayed as numerical values, contour plots, color bands, surface representations, or graphs. All screen displays may be printed or saved in formatted files.

Amperes may be examined for 30 days at no charge. It can then be leased for (Continued on p. 70)



Cathy Weaslenko

Solar 300 will race 150 kilometers (90 miles) on two separate days.

Electric-powered vehicles in the Electric 200, which is open to retrofitted stock cars, will race 200 km (120 mi) in a single day. (To obtain the "500" in the event's name and remind everyone of the enormously successful Indianapolis 500 car race held annually in the United States, SERA fudged the figures—it added the mileage, or rather, the kilometerage, of the three individual races.)

Qualifying heats will determine post position. Qualifying speeds are likely to be in excess of 100 miles per hour (160 kilometers per hour), according to SERA president Ernest Holden. He expects more than 20 vehicles to be entered in each class. In other competitions, vehicles will attempt to set world speed records over closed one-, two-, and five-mile (1.7, 3.3, and 8.3 km) courses.

Other features of the 500 will be exhibits by manufacturers of advanced electric-car technologies, including batteries (such as lithium-air fuel cells and flowing-electrolyte zinc-air units); electric motors (ceramic permanent-magnet disk); and solar cells.

Also on display will be the Demi X-1, an electric vehicle that in one mile can reach

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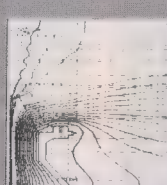


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(Continued from p. 68)

\$8500 per year or purchased for \$23 000, with discounts available until Feb. 28. Contact: Bennetta Benson, Integrated Engineering Software, 347-435 Ellice Ave., Winnipeg, Man., Canada R3B 1Y6, 204-942-5636; or circle 107.

TOY

Laser pointer

For any kind of public speaking—from informal talks to your co-workers to formal presentations to Government officials, from talks conducted in the gloom of a darkened auditorium to the brightness of a Saudi desert—what better pointer to point with than one equipped with a laser diode? The Emphasis Laser Pointers from The Layman's Laser Co. pump out 0.5–0.7 milliwatt of bright red light at a wavelength of 677 nanometers.

With the laser pointer, it's possible to pick out something in virtually any kind of light and from virtually any position with-



out standing next to, or in front of, the object. The light will show up on the brightest light-projector screen, according to the company, and up to 150 feet (45 meters) away in normal office lighting.

On tours of inspection, for example, it's possible to "finger" equipment from a safe distance and without interfering with work in progress. Just take care not to shine the laser for any time on your listeners—and do discourage them from staring into the beam.

Emphasis pointers, each made of rugged aluminum-and-brass that slides into a leather case, come in two models. The \$249 Executive has an anodized black finish with switch and trim rings plated with 24-karat gold. For the more budget-conscious lecturer, the \$219 Professional is anodized to a light gray finish with black trim. Each model—8.5 inches long and 0.75 in. in diameter (22 by 2 centimeters)—weighs 5.5 ounces (155 grams) with two AA batteries supplying power. Contact: The Layman's Laser Co., Box 58770, Seattle, Wash. 98138-1770; 1-800-258-2202; or circle 103.

EDUCATION

Learn technical Japanese

Want to be the only one on your block who knows what the Japanese are up to in technology? The only one at your company? If

you do—and you live in or near Boston and already have some knowledge of the language—you might consider learning to read the technical papers being written in Japan by enrolling next summer in a course offered by the Massachusetts Institute of Technology.

"Technical Japanese for computer scientists and electrical engineers" is now in its fourth year. It is an advanced course; its prerequisites are a command of the basic structure of Japanese (equivalent to two to three years of college Japanese) plus knowledge of computers and computer science or a related field.

Productive relations between the United States and Japan depend upon the exchange of information in the fields of science and technology, pointed out Richard J. Samuels, a professor at MIT and director of its Japan Program. This exchange, however, runs mostly one-way—many Japanese read English, but hardly any Americans read Japanese. "While the Japanese scientist may look to the United States for a wealth of valuable information, for the American scientist, Japan is largely inaccessible—a 'black box,'" said Samuels.

The course will be given under the auspices of the Japan Program, part of the institute's Center for International Studies. This program was established in 1981 to promote dialogue between U.S. and Japanese scientists, engineers, and, more recently, managers.

Tuition for the eight-week course, which runs from June 10 to Aug. 2, is US \$3300. Limited financial assistance is available. The deadline for applying is March 1, with the number of participants limited to 20. Contact: Susan L. Sherwood, Technical Japanese Language Project Administrator, MIT Japan Program, E38-762B, Cambridge, Mass. 03139; 617-253-8095.

COMMUNICATIONS

A trio of forums

The latest in worldwide telecommunications and computer technologies, as well as marketing issues, will be the topics presented at the three conferences on communications organized by the National Engineering Consortium in Chicago. The three-day seminars, ranging from basic to highly technical, are the Western Communications Forum, Feb. 4–6, Phoenix, Ariz.; Eastern Communications Forum, April 29–May 1, Washington, D.C.; and the National Communications Forum, Sept. 30–Oct. 2, Chicago.

In addition, the consortium has organized a quartet of two-day forums on specific topics. They are: "2021 A.D.: Visions of society, technology, information, and communications," March 14–15, Phoenix; "Worldwide personal communications: Call for an industry vision," June 10–11, Rye Brook, N.Y.; "Quality: The requisite for the 90s," June 12–13, Rye Brook, N.Y.; and "Sonet: In our future now," June 13–14, Rye Brook, N.Y. Contact: National Engineering Consortium, 303 East Wacker Dr., Suite 740, Chicago, Ill. 60601; 312-938-3500; fax, 312-938-8787; or circle 105.

Coordinator: Alfred Rosenblatt

CLASSIFIED EMPLOYMENT OPPORTUNITIES

The following listings of interest to IEEE members have been placed by educational, government, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum Magazine*, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

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IEEE encourages employers to offer salaries that are competitive, but occasionally a salary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

Academic Positions Open

University of Illinois at Chicago—Instructorships and Tenure-Track faculty positions in electrical engineering and computer science at both the junior and senior level are available. Rank and salary commensurate with qualifications. An earned Doctorate in EE or CS must be completed by date of appointment, but not for the instructorships. Demonstrated teaching and research abilities are highly desirable. For full consideration, please send resume, list of publications, and the names of at least three references by April 30, 1991, to Dr. Wai-Kai Chen, Head, Department of Electrical Engineering and Computer Science (M/C 154), University of Illinois at Chicago, P.O. Box 4348, Chicago, IL 60680. The University of Illinois is an Affirmative Action/Equal Opportunity Employer.

Texas A&M University. The Electrical Engineering Department has several openings for tenure track faculty at all ranks. Applicants must have a Ph.D. degree. For senior positions, the individuals should have a proven record of scholarly contributions, and for junior positions, demonstrated potential for quality research and teaching is necessary. The salary is competitive and commensurate with qualifications and experience. The Department has 1300 undergraduate students, 350 graduate students and a faculty of 56. Currently the active areas of graduate programs include digital and analog microelectronics, electronic and magnetic materials and devices, electromagnetics, microware engineering, computer engineering, electrooptics, telecommunications, controls, signal processing, electric power systems, and power electronics. Qualified individuals having expertise in any of these research areas are urged to apply. The Department has particular interest in hiring outstanding faculty in the areas of computer engineering, microelectronics, electronic materials, electromagnetics, microwave engineering, power systems automation, solid state electronics and signal processing. Applicants should send a complete resume, including names and addresses of three references to Dr. J.W. Howze, Department Head, Electrical Engineering Department, Texas A&M University, College Station, TX 77843. Texas A&M University is an equal opportunity/affirmative action employer, and actively seeks the candidacy of women and minorities.

Illinois Institute of Technology, Department of Electrical and Computer Engineering invites applications for tenure track and tenured faculty positions in the areas of computer, communication, electromagnetics, and power. Please send resume to Chair of Faculty Search Committee, Department of Electrical and Computer Engineering, Illinois Institute of Technology, Chicago, Illinois 60616. IIT is an equal opportunity/affirmative action employer.

Professor of Optics—The Institute of Optics, University of Rochester, invites applications for a tenure track position as Assistant Professor or Associate Professor of Optics. A Ph.D. degree in Physics, Optics, or Electrical Engineering is required. Particular research interest is optical engineering. The successful candidate will be expected to teach one course per semester

and to pursue a vigorous program of research. Laboratory space and start-up research funds will be provided. The Institute of Optics offers programs leading to the B.S., M.S., and Ph.D. degrees in Optics and has approximately 150 graduate students in residence at the present time. Qualified women and minority persons are especially urged to apply. Send a resume and names of three reference to: Professor Duncan T. Moore, Director, The Institute of Optics, University of Rochester, Rochester, New York 14627. An Equal Opportunity Employer.

University of California, Davis Faculty Positions in Electrical Engineering and Computer Science. The Department of Electrical Engineering and Computer Science at UC Davis invites applications for various tenure track positions. The primary areas of interest are Computer Engineering and Microprocessor Application; Electronic Circuits; Image Processing and Computer Vision; and Optoelectronics. One position in the area of image processing and one in the area of optoelectronics. One position in the area of image processing and one in the area of optoelectronics is open to all ranks. Other positions are at the assistant professor level. The department, with 53 faculty members and 180 full-time graduate students, is experiencing rapid growth. Our College is the nation's sixteenth largest producer of engineering Ph.D.'s in a University which has the nineteenth largest extramural research funding. Salary and benefits are extremely attractive. Davis is a pleasant, family-oriented community near Sacramento, within easy driving distance to Silicon Valley, the Lawrence Livermore National Laboratory, San Francisco, the Pacific Ocean, and the Sierra Nevada Mountains. We are seeking individuals with strong records of teaching and research and with ambitious plans. Senior appointments require outstanding records of achievement; junior appointments must show evidence of great promise. All faculty are expected to have a strong commitment to teaching at all degree levels, and to demonstrate the ability to attract significant research support. The positions require a Ph.D. or equivalent, and are open until filled; but in order to assure consideration, applications should be received by March 1, 1991. Send a resume and the names of at least three references to: Professor S. Louis Hakimi, Chair, Attention: Faculty Search Committee, Department of Electrical Engineering and Computer Science, University of California, Davis, CA 95616. The University of California, Davis, is an equal opportunity/affirmative action employer.

California Institute of Technology. The Computation and Neural Systems (CNS) program at Caltech is conducting a search for a tenure-track Assistant Professor on the engineering side of CNS, for which the term of initial appointment is normally four years. CNS is an interdisciplinary Ph.D. program established in 1986 that brings together engineers and scientists who are applying ideas from neurobiology to the development of new computational devices and systems and biologists who are investigating how computation is done in the nervous system. Areas of interest include Motor Control, Learning, Speech, Vision and Artificial Neural Networks. The appointee will be expected to develop strong research activity, and to teach courses in his or her specialty. Applicants should send a resume, including list of publications, a brief statement of research accomplish-

ments and goals, and the names of at least three references to Professor Y. Abu-Mostafa, Caltech 116-81, Pasadena, CA 91125. Caltech is an equal-opportunity employer and it specifically encourages women and minorities to apply.

Purdue University School of Electrical Engineering invites applications for tenure-track faculty positions at all ranks. Primary need is for faculty with specialization in the areas of computers, microelectronics, and optics; but all specialties will be considered. Responsibilities will include both teaching and research. Salary is commensurate with qualifications and experience. Applicants must possess a doctorate degree. Send a resume, including a statement of teaching and research interests and a list of three (3) references, to: Head, School of Electrical Engineering, Purdue University, West Lafayette, IN 47907. Purdue University is an Equal Opportunity/Affirmative Action employer.

The Center for Advanced Computer Studies. The Center is seeking qualified candidates for tenure track research faculty positions in Computer Science/Engineering, beginning Fall 1991. Associate Professor and Professor candidates must hold Ph.D.s in the field, and have established research publications and grant records. Exceptional Assistant Professor candidates will also be considered, must hold Ph.D.s in the field, and must have strong research potential. Consideration will be given to all qualified candidates, but preference areas of interest are: software engineering, computer networks, operating systems, databases, computer architecture, artificial intelligence, and theoretical computer science. The Center conducts programs leading to the MS/PhD degrees in Computer Science and Computer Engineering. These programs currently enroll 210 students, with approximately 100 declared PhD candidates. A large number of PhD fellowships and assistantships are available, with stipends of up to \$18,000 per year, up to 4 years. Typical faculty teaching load is 2 courses per year and a continuing research seminar, with solid travel support. Substantial State Educational Fund monies are available to establish research programs. The University is located in Acadiana, short distance West of New Orleans. Send resumes to: Dr. Michael C. Mulder, Director, The Center for Advanced Computer Studies, University of SW Louisiana, P.O. Box 44330, Lafayette, LA 70504; email: cathy@cacs.usl.edu. Review of applications will begin February 1991. The University of SW Louisiana is an affirmative action/equal employer.

Rice University Department of Electrical and Computer Engineering invites applications for faculty positions in the areas of robotics, signal processing, and computer systems. Applicants in the area of robotics should be interested in space or undersea applications and be able to lead a robotics laboratory. Applicants in signal processing should have a background in basic signal and systems with interests in image and multidimensional processing. Applicants in the computer systems area should have interests in the general areas of computer architecture, operating systems, and parallel computing. Outstanding applicants working in related areas will also be considered. Rice University is a small, private university with a long history of excellence in both research and teaching. It is located in Houston, Texas, clean

CLASSIFIED EMPLOYMENT OPPORTUNITIES

modern city with affordable housing and excellent fine arts. The Department of Electrical and Computer Engineering has close ties with the Computer Science Department, Mathematical Sciences Dept. and the Mechanical Engineering Department, all being in the School of Engineering. The Robotics Laboratory has excellent facilities and research ties with NASA as well as other groups. The Computer Systems Laboratory provides research focus in computer architecture, operating systems, parallel algorithms, software, performance evaluation, VLSI design, and other related areas. The Signal Processing Group has a long history of research in algorithms, filter design, statistical signal processing, and biomedical applications. Rice has an NSF funded Science and Technology Center for Research on Parallel Computation that provides facilities and coordination for all groups. Applicants should submit their resume, a summary of their research accomplishments, and the names of at least three references to the Chairman of the Department of Electrical and Computer Engineering, Rice University, P.O. Box 1892, Houston, TX 77251-1892. Rice University is an equal opportunity/affirmative action employer.

Electrical Engineering: Tenure track position available July 1, 1991 at the assistant professor level (higher rank considered based on experience). We are looking for someone with a background in power systems and/or electromechanical energy conversion. A strong commitment to undergraduate teaching is essential as is a desire to become involved in our broad-based lab oriented curriculum. Ph.D. preferred but will consider M.S. with significant relevant experience. U.S. citizenship or permanent residency strongly preferred. Norwich University is located in an area of central Vermont that offers small-town or rural living with good schools and outstanding recreational opportunities. Send resume and references to: Prof. William Till, Chairman, Dept. of Electrical Engineering, Norwich University, Northfield, VT 05663. Position open until filled. EOE, women encouraged to apply.

Rensselaer Polytechnic Institute, Department of Electrical, Computer, and Systems Engineering, invites applications for tenure-track faculty positions at all levels. Specific areas of interest include: (1) optical communications and networks; optical computing; (2) computer engineering and architecture, especially real-time systems and neural networks; (3) discrete-event systems and Petri net analysis with applications to manufacturing and networks; (4) plasma diagnostics and electromagnetics with an emphasis on active particle beam based diagnostics for magnetic confinement experiments. The ECSE Department is the largest academic unit at RPI and has a rich tradition of research and education. The department is seeking to add faculty who bring an innovative approach to research and teaching. Active programs in computer engineering, solid-state electronics and integrated circuit design, control systems, robotics and automation, information and decision systems, communications and signal processing, electronics and circuits, and fusion plasma systems contribute to a dynamic research environment. In addition to the extensive research facilities of the department, there are opportunities to initiate or participate in interdisciplinary research programs in one of the major research centers of the School of Engineering, including the Center for Integrated Electronics, Rensselaer Design Research Center, Center for Manufacturing Productivity and Technology Transfer, the NASA Center for Intelligent Systems in Space Exploration and the New York State Center for Advanced Technology and Robotics. New faculty are eligible for special arrangements including summer support, equipment, graduate student support, and reduced teaching load in order to encourage growth of their research programs. Applications or request for more information should be directed to: Dr. Arthur C. Sanderson, Chairman, Dept. of Electrical, Computer and Systems Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180-3590. RPI is an affirmative action/equal opportunity employer and encourages applications from women and minorities.

The University of Toledo. The Electrical Engineering Department invites applications for

a tenure track position in VLSI Systems beginning September 1991. A Ph.D. in electrical engineering or a related area required. Responsibilities include undergraduate and graduate teaching and research. Candidates with a background and an interest in VLSI or IC CAD tool development are especially encouraged to apply. State University with 24,000+ students including 2200+ students in B.S., M.S., and Ph.D. engineering programs. Rank and salary are open. Send applications with resume containing names and addresses of three (3) references by February 28, 1991 to Dr. Kai Fong Lee, Chairman of Electrical Engineering Department, The University of Toledo, Toledo, OH 43606-3390. Non-US citizens must indicate their immigration status. The University of Toledo is an Equal Opportunity/Affirmative Action Employer.

University of Arizona. The University of Arizona Electrical and Computer Engineering Department invites applications for tenure track faculty appointments for the 1991-92 academic year. Preference will be given to applicants at the Assistant Professor level, but exceptional candidates at higher levels may also be considered. In addition to an earned doctorate and a commitment to effective teaching at both the undergraduate and graduate level, it is essential that candidates have outstanding research achievement and/or potential and the commitment and ability to establish an externally sponsored research program. Technical areas of particular interest for 1991-92 recruiting are computer engineering including AI/robotics, signal and image processing including pattern recognition/neural networks, telecommunications, and microelectronics including analog circuits. Applicants should send a resume, a statement of teaching and research interests, and a list of three references to: Prof. K.F. Galloway, Department Head, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ 85721. Applications will be reviewed starting January 15, 1991 and will be received until open positions are filled. The University of Arizona is an Equal Opportunity/Affirmative Action Employer and specifically invites women and minorities to apply.

Harvey Mudd College, Electrical Engineering. Applications are invited for a tenure track position in the Engineering Department, beginning Fall Semester 1991. Appointment at the Assistant Professor level is anticipated. The position requires demonstrated capabilities in two or more of the following areas: analog/digital electronics, VLSI, and materials. Responsibilities will include teaching in a unified engineering curriculum, developing courses, and supervising industrially sponsored projects in the Engineering Clinic. Continuing professional growth and development through research or consulting is expected; excellent opportunities exist in the local area. A doctorate is required for the position. Industrial experience is desirable. Reply to: Electrical Engineering Search, Attention: John I. Molinder, Chairman of Engineering, Harvey Mudd College, Claremont, CA 91711. Send application by March 1, 1991. Harvey Mudd College is an equal opportunity/affirmative action employer.

The Department of Electrical Engineering invites applications and nominations for 3 tenure track positions in the area of Control Theory at the rank of Assistant or Associate Professor. Qualifications should include an outstanding academic record, significant achievements in original research, sincere interest in teaching, and a Doctorate in Electrical Engineering or related area. Application deadline is February 28, 1991. Please send a resume and the names and addresses of at least three professional references to: Professor T.E. Bullock, Department of Electrical Engineering, University of Florida, Gainesville, FL 32611. Citizens of foreign countries please indicate US Visa status. The University of Florida is an Affirmative Action Employer. Women and minorities are encouraged to apply. According to Florida law, applications and meetings regarding applications are open to the public on request.

Faculty Positions in the Electrical Engineering Department at The University of North Carolina at Charlotte, Charlotte, NC 28223. The Electrical Engineering Department at the University of North Carolina at Charlotte invites appli-

cations for two tenure-track positions at the Assistant, Associate, or Full Professor level. Areas of interest include signal and image processing/communications (including optical signal processing and telecommunications), and microelectronics (including optoelectronics, process technology, system integration, nanometric devices, and analog/digital VLSI design). Positions begin Fall of 1991. The University of North Carolina at Charlotte is one of the largest institutions of the UNC system. It has over 14,000 students, including 2,125 graduate students in the six colleges. The department is one of five in the College of Engineering and currently enrolls 350 students, of which 50 are graduate students and Postdoctoral Research Associates. Computer facilities include micros, minis, workstations and free access to Cray YMP supercomputer. The laboratory facilities include a class 100 clean room with complete integrated circuit and microstructure fabrication capabilities, laboratories for measuring the electrical properties of the insulator-semiconductor surface, computerized IC test facilities, laser electro-optic laboratory, dry processing laboratory for VLSI fabrication, and MBE laboratory for quantum well superlattice and optoelectronic materials. As a participating institution of MCNC (Microelectronics Center of North Carolina), the faculty have access to the MCNC facilities with capabilities of submicron IC design, fabrication, test, and semiconductor materials analysis. Charlotte is the largest city in the Carolinas and offers good schools and attractive housing. The 100,000 sq. ft. engineering building and a 75,000 sq. ft. applied research building are located adjacent to the 2,800 acre University Research Park. Various forms of career development support are available. Applicants should have a Ph.D. degree or equivalent and have commitment to teaching and pursuing research. Industrial and research experience is desirable. Rank and salary commensurate with experience. Applications will be accepted until March 1, 1991. Initial screening begins February 1, 1991. Applications, including a resume and four references, should be sent to: Rafic Makki, Chairman, Search Committee, Electrical Engineering Department, UNC-Charlotte, Charlotte, NC 28223. UNC-Charlotte is an equal opportunity affirmative action employer, and complies fully with the Immigration Reform and Control Act of 1986.

Electrical Engineering. Faculty Openings. Louisiana Tech University. Applicants with an earned doctorate will be judged on effective teaching, ability to improve the growing graduate program, and potential for initiating funded research. Particular emphasis will be given to the areas of digital and microprocessor circuits, computer architecture, and parallel processing. All materials, including letters from references, transcripts, and indication of visa status, etc. will be considered at the first of each month, starting December 1, 1990, until all positions are filled or until final cutoff on May 31, 1991. Send resume and three references to: EE Search, College of Engineering, Louisiana Tech University, Ruston, LA 71272. Louisiana Tech University is an Equal Education and Employment Institution.

Electronic Engineering Technology—Penn State Harrisburg. Full-time faculty position starting August 1991. Tenure track appointment for qualified applicant. Teaching assignments in junior/senior level electrical engineering technology program and in an evening master of engineering program. Competitive salary. Qualifications: M.S.E.E. or Ph.D., relevant teaching and industrial experience in electric/electronic circuits, power systems, industrial electronics, and switching circuits. Related computer hardware and software experience's highly desirable. Applications will be reviewed starting March 15, 1991 and will continue until the position is filled. Penn State Harrisburg is an upper division college and graduate center located 8 miles southeast of the State Capital at Harrisburg. Send resumes to Dr. William A. Welsh, Jr., Box IEEE, Penn State Harrisburg, Route 230, Middletown, PA 17057. An Affirmative Action/Equal Opportunity Employer. Women and Minorities Encouraged To Apply.

Electrical and Computer Engineering—St. Mary's University invites applications for a tenure-track Assistant Professor position in Electrical and Computer Engineering beginning August 1991. Candidates should have an earned Ph.D. or equivalent in ECE and a strong commitment to excellence in teaching and research.

The successful applicant must have a broad background so as to be able to teach graduate and undergraduate courses and conduct research in several areas such as Computer Architecture and Parallel Processing, Networks and Distributed Processing, Computer Vision and Speech Processing, Artificial Intelligence, Software Engineering, and General Electrical Engineering. Applications including resume and three letters of reference must be sent to Dr. Abe Yazdani, Chairman, Department of Engineering, One Camino Santa Maria, San Antonio, TX 78228-8534. (512) 436-3305. The position is subject to approval. St. Mary's is an equal opportunity affirmative action employer.

Faculty Position. The Department of Biomedical Engineering of the University of Akron is seeking applicants at the Assistant/Associate Professor level for Fall 1991. A Ph.D. in engineering is required for this tenure-track position with preferred areas in Neural Networks, Biocircuits, Sensory Systems or Biomaterials. The University of Akron is the third largest state-assisted university in Ohio. Send resumes and names, addresses and phone numbers of three references to: Dr. Stanley E. Rittgers, Chmn. Search Committee, Dept. Biomedical Engineering, The University of Akron, Akron, OH 44325-0302. Applications will be reviewed monthly until the position is filled. The University of Akron is an Equal Education and Employment Institution.

Electronics Instructor is being hired at Centralia College. Must have proven record in the following areas: AC/DC circuit analysis; digital logic through micro-computer elements; radio frequency communications including digital transmission; semiconductor devices and applications; digital and analog industrial applications; troubleshooting to the component level; and soldering technologies. A B.S.E.E. is desirable and strong industrial record is required (2 yrs minimum). Interested and qualified applicants must submit an application form, structured questionnaire, letter of application, comprehensive resume, transcripts and 3 current letters of recommendation to: Personnel Officer, Centralia College, 600 W. Locust, Centralia, WA 98531 (206) 736-9391. Closes 4/1/91. AA/EOE.

Dartmouth College, Thayer School of Engineering. The Thayer School of Engineering at Dartmouth College invites applications for tenure-track appointments. Of special interest are candidates with experience in VLSI and digital system design, but outstanding candidates in all areas of computer engineering and computer architecture are encouraged to apply. Current research at Dartmouth has focused on the design of special purpose computational structures, with the intent of supporting areas of scientific research that can benefit from customized computing power. A Rapid Prototyping Laboratory is being developed for the construction of these systems; candidates with an interest in developing prototype systems are particularly encouraged to apply. Interested persons should submit a resume and names of three references to Professor Barry S. Fagin, Thayer School of Engineering, Dartmouth College, Hanover, NH 03755. Review of applications will begin in January 1991, and continue until the positions are filled. Dartmouth College is an Equal Opportunity/Affirmative Action employer and encourages applications from women and members of minority groups.

Positions for Visiting Professors, Post-Doctoral Fellows, and Research Associates are available in the Electrical and Computer Engineering Department of Concordia University, Montreal, in the following areas: Robotics, Signal Processing, Control Systems, Circuit Theory, VLSI, Semiconductor Physics, Microwave Transmission, Antennas, Electromagnetic Compatibility, Distributed Computing, VLSI Algorithms, Design Automation for VLSI, and Computational Graph Theory. Interested parties should send their curriculum vitae to: Dr. P.D. Ziogas, Chairperson, Electrical and Computer Engineering, Concordia University, 1455 de Maisonneuve Blvd West, Room 915-7, Montreal, Quebec, H3G 1M8.

Electrical and Computer Engineering—Applications are invited for a tenure-track faculty position at the Assistant Professor Level. Interested candidates should have a background and interest in teaching and research in a technical area encompassing communica-

tions, signal processing, and computer engineering. Successful applicants will be expected to teach undergraduate and graduate courses in these areas and to develop a graduate research program which includes M.S. and Ph.D. students. Applicants must have a doctoral degree or be near completion of a doctoral program. Rank and salary commensurate with qualifications. Send resume and names of at least three references to: Dr. Russell J. Niederjohn, Chairman, ECE Department, Marquette University, Milwaukee, WI 53233. Marquette University is an equal opportunity/affirmative action employer.

Electronic Engineering Technology. Mankato State University invites applications for tenure track position in ABET accredited four-year program. An earned Doctorate degree is preferred but serious consideration is given to an MS degree with recent industrial experience in electrical engineering. Rank and salary are negotiable. Salaries are competitive. Preference is given to individuals with interests in power electronics and electromechanics. The Department offers stimulating professional environment, excellent computer and shop facilities as well as newly equipped microprocessor, communications, control, microelectronics and electromechanics laboratories. Mankato State University has an enrollment of 16,000 students and is located 70 miles southwest of the Minneapolis/St. Paul metropolitan area. Send resume indicating teaching interests, experience and names of three references with phone numbers to: Dr. Carl Gruber, Chairman, Department of Electrical Engineering and Electronic Engineering Technology, MSU Box 215, Mankato State University, Mankato, MN 56002-8400; (507) 389-6536. Deadline March 31 or until filled.

The Johns Hopkins University, Department of Electrical and Computer Engineering, invites applicants for tenure-track faculty positions at the Assistant or Associate Professor level, in the solid state/quantum electronics area and in computer engineering. Candidates for Associate Professor appointments are expected to have significant research records and demonstrated ability to develop funded research programs. Candidates for Assistant Professor appointments are expected to show strong research potential. All candidates should have a doctorate (preferably in electrical engineering) and a strong commitment to teaching and research. Applications should be sent to Professor C.R. Westgate, Chair, Department of Electrical and Computer Engineering, The Johns Hopkins University, Baltimore, MD 21218. The Johns Hopkins University is an equal opportunity/affirmative action employer.

Electrical Engineering Technology: Western Kentucky University is seeking applicants for a tenure-track faculty position available August 1991. (Qualifications: M.S. or Ph.D. in Electrical Engineering, three years full-time engineering experience in American industry and one year full-time teaching experience in a TAC/ABET level Engineering or EET Program. Professional Engineering registration desirable. A commitment to teaching excellence and responsiveness to student needs are essential. Duties: Undergraduate teaching, university and public service, and research. Send letter of application, resume, three letters of reference and transcripts to Office of Academic Affairs, EET Search, Western Kentucky University, Bowling Green, KY 42101. Women and minorities are encouraged to apply. Affirmative Action/Equal Opportunity Employer.

The Department of Electrical Engineering at The University of Tulsa has a tenure track position beginning Fall 1991. A specialist in modern digital systems including high performance computer architectures, digital communications (both personal and computer) and VLSI design and computer assisted engineering is particularly needed, but applicants from other related research areas are encouraged to apply. Industrial experience in research and development is especially desirable. This position requires an earned doctorate, teaching experience at the undergraduate level, and the ability to initiate and participate in interdisciplinary research programs both within the University and with local industry. Rank and salary will be commensurate with qualifications. Departmental computer facilities include an HP/Apollo workstation complex and a PC-base RING in the undergraduate laboratories. The Department is an integral part of a campus wide com-

puter network with access to college workstations and mini super computer, the University mainframe, and the national networks. The University of Tulsa is a private, selective admission institution of 3000 undergraduate and 1500 graduate students, located in an urban community of over half a million. Interested persons should send resume, including names, addresses and phone numbers (or E-mail address) of three references by April 1, 1991 to: Dr. Gerald R. Kane, Professor and Chair, Department of Electrical Engineering, The University of Tulsa, 600 S. College, Tulsa, OK 74104. The University of Tulsa is an affirmative action/equal opportunity employer.

Assistant Professor, Department of Mechanical Engineering, McGill University. Applications are being sought for a tenure-track position in experimental robotics, with complementary expertise in mechanical design. Candidates should have demonstrated competence in combining theory with instrumentation and experimentation. A working knowledge of robotic systems is required, including actuators, sensors, interfaces, and real-time computational architectures. An ability to apply a strong theoretical base in mechanics, signal processing, and control to produce advanced experimental robotic demonstrations is essential. The position features a reduced teaching commitment, concentration on research, and an NSERC Operating Grant for yearly support of some research activities. The candidate will be expected to set up his or her own research laboratory, but will also have the opportunity to participate in ongoing research in such areas as tele-robotics and microrobotics. In accordance with Canadian immigration requirements, this position is offered in the first instance to Canadian citizens and permanent residents. Interested persons should send their curriculum vitae and the names of three referees by March 15, 1991 to: Prof. A. Ahmed, Chairman, Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, Montreal Quebec H3A 2K6.

University of Missouri-Columbia. The Department of Electrical and Computer Engineering invites applications for tenure-track positions at the assistant, associate, or full professor level in the areas of computer engineering or computer science. Responsibilities include teaching undergraduate and graduate courses, student advising, and developing and conducting sponsored research programs. Candidates must have an earned doctorate in Electrical and Computer Engineering, Computer Science or related discipline, and the potential for, and commitment to, developing sponsored research. The department currently has strong research programs in computer vision/pattern recognition, materials and solid state, and power electronics. Interested applicants should send resume, a description of teaching and research interests, and a list of three references to: Jon Meese, Chairman, Department of Electrical and Computer Engineering, University of Missouri-Columbia, Columbia, MO 65211. Immigration status of non-United States citizens should be stated. Affirmative Action/Equal Opportunity Employer.

The Bradley Department of Electrical Engineering of Virginia Polytechnic Institute and State University invites applications for several tenure track faculty positions. Greatest needs are in the areas of electronic materials (a joint position with Materials Engineering Department) and communications with emphasis on high frequency electronics. Consideration will be given to applicants in all areas at the Assistant and Associate Professor level. Applicants must have an earned doctorate, be interested in undergraduate and graduate teaching, and be willing to secure research sponsorship. Virginia Tech is Virginia's land grant university offering degrees through the Ph.D. Send complete resume with references and employment/citizenship status to: Prof. W.L. Stutzman, Chairman, Personnel Committee, Bradley Department of Electrical Engineering, Virginia Tech, Blacksburg, VA 24061-0111. Applications will be accepted until April 15, 1991, or until suitable candidates are selected. Virginia Tech is an Equal Opportunity/Affirmative Action Employer.

Chairman, Computer Science Department. The Department of Computer Science at Concordia University is inviting applications for the position of Chairman of the Department. One of five departments in The Faculty of Engineering and

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Computer Science, the Department is one of the largest in Canada and strongly research oriented. It offers undergraduate and graduate programs (to the PhD level) to some 450 full-time and 340 part-time students. There are 27 full-time faculty members. Current direct research income exceeds \$1,500,000 per year. The major areas of research include: pattern recognition and machine intelligence, parallel and distributed processing, VLSI architectures and algorithms, combinatorial and algebraic computing, numerical analysis and scientific computing, logic programming, database systems. The Department houses the Centre of Pattern Recognition and Machine Intelligence and is a member of the Centre de Recherche en Informatique de Montreal, a joint Research Centre in Computer Science of the four Montreal Universities. The Department has research laboratories for distributed computing, character recognition, mathematical computing, scientific computing, micro-processor systems, etc. The position will interest senior academics with an excellent record in research and teaching who are prepared to and capable of assuming a leadership role in the development of Computer Science in the Faculty, the university, and nationally. Although the language of instruction is English, fluency in French will be a major advantage. Applications with Curriculum Vitae should be sent to: Dr. M.N.S. Swamy, Dean, Faculty of Engineering and Computer Science, Concordia University, 1455 Boulevard de Maisonneuve O., Montreal, Quebec, H3G 1M8 CANADA. In accordance with Canadian immigration requirements, this advertisement is directed, in the first instance, to Canadian citizens and permanent residents. If no suitable candidates are available, other candidates will also be considered.

Stanford University, Telecommunications, Senior Faculty Position. The Department of Electrical Engineering of Stanford University is seeking candidates for a tenured position in Telecommunications. The individual must seek should have greatest strength and experience with systems, and in particular should be knowledgeable of the commercial telecommunications industry and its needs. Candidates should have excellent knowledge of theory and a proven skill in implementing such knowledge in "proof of concept" demonstrations. Areas of interest include but are not limited to: wireless communications, intelligent networks, fiber optics, switching systems, multimedia and broadband networks, and large-scale telecommunications software problems. The Department prefers a seasoned individual, possibly with industrial experience, and having the potential to play a major role in a larger telecommunications effort at Stanford. Applicants should have earned a Ph.D., demonstrated research ability, and a strong interest in graduate and undergraduate teaching. Stanford University is an Equal Opportunity Employer and welcomes applications from women and members of minority groups. Please submit, no later than April 1, 1991, a detailed resume, a publication list and the names of five references to Professor Joseph W. Goodman, Chairman, Department of Electrical Engineering, Stanford University, Stanford, CA 94305-4055.

University of Illinois at Urbana-Champaign. The Department of General Engineering, University of Illinois at Urbana-Champaign, invites applications for a tenure-track faculty position in one of the following areas: computational geometry, solid modeling, or computer-aided and computational design, design theory and methodology, large-scale systems/manufacturing systems, artificial intelligence/operations research, or robotics and control. The appointment will normally be made at the assistant professor level, but a senior level appointment with tenure is also available for a person of recognized national and international stature. An earned Ph.D. degree in engineering or allied discipline is required. The candidate must be committed to teaching at the undergraduate and graduate levels as well as developing a high quality, externally supported program of research. Salary is commensurate with education and experience. The starting date is August 21, 1991. The Department has 23 faculty, 630 students at the undergraduate and graduate levels, and research programs in engineering design, robotics and control, design and manufactur-

ing systems, artificial intelligence/operations research, biomechanics, and nondestructive evaluation. Applications, including a letter of interest, a curriculum vitae, complete publication list, dissertation abstract, undergraduate and graduate transcripts and the names of three references should be sent to: Professor Thomas F. Conry, Head, Department of General Engineering, University of Illinois at Urbana-Champaign, 104 South Mathews Avenue, Urbana, Illinois 61801; (217) 333-2730. In order to ensure full consideration, applications must be received by February 20, 1991, though applications will be considered until the positions are filled. Some interviews may be conducted before the deadline, but no finalists will be established before the deadline. The University of Illinois is an Affirmative Action/Equal Opportunity Employer.

The J. Bennett Johnston Sr. Center for Advanced Microstructures and Devices (CAMD) at Louisiana State University, Baton Rouge, LA seeks a Staff Scientist (Associate Professor-Research) for X-ray Lithography. The centerpiece of CAMD is a 1.2 to 1.4 GeV electron storage ring optimized for the production of soft x-rays. Responsibilities will cover organization of the programs in x-ray lithography, micromachining and x-ray optics at CAMD. Ph.D. is required in engineering or science. Experience in synchrotron radiation, soft x-ray optics and micromachining is desired. A letter of application, a resume, list of publications and three references should be sent to Dr. Volker Saile, CAMD, Louisiana State University, 3990 West Lakeshore Dr., Baton Rouge, LA 70803. Anticipated hire date is March 15, 1991. "Pending Final Approval." Application deadline is March 1, 1991 or until suitable applicant is found. LSU is an Equal Opportunity University.

Graduate Research Assistantships in Electrical Power Systems are available for graduate students pursuing the M.S. or Ph.D. degrees at Clemson University. Funding is available through Clemson University Electric Power Research Association (CUEPRA), NSF, and research contracts with power companies. Research assistantships consist of a monthly stipend and tuition fee reduction. For United States citizens, industrial fellowships are also available. To be considered, submit transcript and GRE record to Dr. Adly A. Girgis, Department of Electrical & Computer Engineering, Clemson University, Clemson, SC 29634-0915. An Equal Opportunity/Affirmative Action Employer.

Boston University. The Department of Electrical, Computer and Systems Engineering at Boston University seeks applications for five faculty positions in the areas of electronic devices, solid state physics, computer architecture and VLSI, electromagnetics and software engineering. Application areas of particular interest include novel electronic and magnetic devices, parallel computing architectures, hardware implementation of neural networks, microwaves and radar, electromagnetic simulations, and embedded systems. All positions are for tenure track or tenured appointments starting in September 1991. An earned Ph.D. in a relevant discipline is required. Faculty are expected to develop a program of funded research in their area of expertise. Boston University is located in the heart of the Boston academic community along the Charles River, with easy access to the outstanding scientific, cultural and tourist attractions of the city. The Department has 30 faculty and approximately 50 Ph.D., 250 MSc and 700 BSc majors. Opportunities exist for collaboration with other colleagues in the Boston area, as well as with the leading electronics and software companies in the area. Applicants should send their curriculum vitae to Professor Thomas G. Kincaid, Chairman, Department of Electrical, Computer and Systems Engineering, College of Engineering, Boston University, Boston, MA 02215. Boston University is an Equal Opportunity/Affirmative Action Employer.

The Bradley Department of Electrical Engineering and the Department of Materials Engineering of Virginia Polytechnic Institute and State University invites applications for a joint appointment in the Electrical Engineering and Materials Engineering Departments. The Associate Professor position will be half-time in

each department with teaching and research responsibilities in both. The Bradley Department of Electrical Engineering has 55 faculty, 1100 undergraduate students, and 300 graduate students. Annual research expenditures exceed \$4 million. The EE Department has many research and teaching laboratories including the Electronic Materials and the Hybrid Microelectronics Laboratories. The Department of Materials and Engineering consists of 13 faculty and approximately 80 undergraduate and over 40 graduate students. The curriculum includes topics in the areas of ceramic, metallic, polymeric, electronic and composite materials. Current research funding is approximately \$1.4 million annually. Many opportunities exist for interdisciplinary research with centers on campus performing related research. Applicants must have an earned doctorate, be interested in undergraduate and graduate teaching, and be willing to secure research sponsorship. Virginia Tech is Virginia's land grant university offering degrees through the Ph.D. Applications from members of minority groups and women are encouraged. Send complete resume with references and employment/citizenship status to: Professor W.L. Stutzman, Chairman, Personnel Committee, Bradley Department of Electrical Engineering, Virginia Tech, Blacksburg, VA 24061. Applications will be accepted until May 15, 1991, or until suitable candidates are selected. Virginia Tech is an Equal Opportunity/Affirmative Action Employer.

FAMU/FSU College of Engineering. The Department of Electrical Engineering of the Florida A&M University/Florida State University (FAMU/FSU) College of Engineering invites applications for anticipated tenure-track positions at all ranks. Candidates with a Ph.D. (electrical engineering preferred) and specialization in the areas of magnetics, image processing, digital system simulation, digital communications and digital control are encouraged to apply, but all specialties will be considered. Successful candidates will be expected to teach undergraduate and graduate courses and develop active research programs. Salary is commensurate with qualification and experience. FAMU and FSU, both in Tallahassee, (the capital of Florida), have a combined enrollment of over 34,000 students. The EE Department has 14 faculty members, 600 undergraduates and 65 masters students. A PhD program has been proposed and is anticipated in 1991. The undergraduate program is ABET accredited. Interested persons should send complete resume, description of research interests and the names and addresses of three references to Dr. B.W. Kwan, Department of Electrical Engineering, P.O. Box 2175, Tallahassee, FL 32316-2175. Applications must be received by February 28, 1991. By Florida law, all application transactions are open to public request. FAMU/FSU College of Engineering is an Affirmative Action/Equal Opportunity Employer. Women and minorities are encouraged to apply.

Assistant Professor. The Department of Electrical Engineering is seeking applications for three (3) tenure track faculty positions starting in August 1991. One position is in the area of Computer Engineering with emphasis in Software engineering and microcomputer applications, second position is in Image and Signal Processing, the third position is in Power Systems with competence in EM Theory or Control Systems. Applicants with refereed publications are preferred. The applicant should have a Ph.D. degree in Electrical Engineering and/or Computer Engineering. Responsibilities include teaching graduate and undergraduate courses in areas of specialization, develop related laboratories, advise and supervise student design projects, attract and execute funded research, generate refereed publications and promote public service. Either U.S. citizen or lawfully admitted resident aliens are eligible to apply. Applications with recent resume should be sent by April 1, 1991 to Dr. S.S. Devgan, Head, Department of Electrical Engineering, Tennessee State University, 3500 John A. Merritt Blvd., Nashville, TN 37209-1561. TSU is an Equal Opportunity/Affirmative Action Employer M/F.

University of Colorado at Boulder. The Department of Electrical and Computer Engineering invites applications for several tenure-track faculty positions. Areas of specialization include, but are not limited to, software engineering, communications, control systems, atmospheric remote sensing, and optoelectronics. Applicants must have a doctoral degree in

Electrical Engineering, Computer Engineering, Computer Science, or related fields. Preference will be given to candidates at the Assistant Professor level, but candidates at all levels will be considered. The University of Colorado at Boulder has a strong institutional commitment to the principle of diversity in all areas. In this spirit, we are particularly interested in receiving applications from a broad spectrum of people, including women, members of ethnic minorities and disabled individuals. Applications of these positions should be sent to: Prof. William Waite, Chairman, Dept. of Electrical and Computer Engineering, University of Colorado, Campus Box 425, Boulder, CO 80309-0425. Application deadline is April 30, 1991.

Concordia University. Department of Electrical and Computer Engineering. The Department of Electrical and Computer Engineering invites applications for two tenure-track faculty positions in Electrical and Computer Engineering at the assistant professor level. One position is in the hardware area with emphasis on digital systems design, computer architecture, and neural network architecture. The other position is in the software area with emphasis on networking and protocols, distributed/parallel processing, software engineering, system software design, integrated systems, compiler and programming languages, and neural networks. Strong candidates in related areas will also be considered. Responsibilities include graduate and undergraduate teaching, research and supervision of graduate students. Candidates should have a Ph.D. in Electrical or Computer Engineering or Computer Science, and a strong interest in both research and teaching. The department currently has twenty-four full-time faculty members and has strong graduate and undergraduate programs. Applicants should send a resume and names of at least three references to: Dr. P.D. Ziogas, Chairperson, Department of Electrical and Computer Engineering, Concordia University, 1455 de Maisonneuve Blvd. West, Montreal, Quebec H3G 1M8. FAX: (514) 848-2802. In accordance with Canadian Immigration requirements, priority will be given to Canadian citizens and permanent residents of Canada. We also invite and encourage applications from female candidates.

Southern Methodist University. Department of Computer Science and Engineering (CSE) invites applications for faculty positions at the Associate and Full Professor levels. Applicants should have an outstanding funding and research record with a strong commitment to teaching. Experienced applicants at the junior faculty level with a proven track record of research may also be considered if the senior position is not filled. SMU is a private university with approximately 9,000 students. CSE is in the School of Engineering and Applied Science, where a close working relationship exists with the Department of Electrical Engineering. CSE presents a balanced program of research and education at all levels and has been offering Ph.D. degrees since 1970. The Department has extensive contacts with computer-related and engineering-oriented industrial firms that distinguish Dallas as one of the top centers for high technology. Applicants should send a complete resume, including the names of at least three references to: Margaret H. Eich, Chair of Recruitment Committee, Department of Computer Science and Engineering, Southern Methodist University, Dallas, TX 75275-0122. SMU is an equal opportunity/affirmative action employer. Applications from women and minorities are particularly encouraged. Applications will be accepted until April 1, 1991.

Southern Methodist University. Department Chair, Department of Computer Science and Engineering. Nominations and applications are invited for the position of Professor and Department Chair of the Department of Computer Science and Engineering at Southern Methodist University. Applicants must have a Ph.D. in Computer Science, Computer Engineering, or related discipline. Candidates must have demonstrated excellence in research with a substantial grant record and a strong commitment to teaching. The anticipated date of appointment is August 1991. SMU is a private university in Dallas, Texas with approximately 9,000 students. CSE is in the School of Engineering and Applied Science, where a close working relationship exists with the Department of Electrical Engineering. The department is growing and presently has fourteen faculty positions. CSE presents a balanced program of

research and education at all levels and has been offering Ph.D. degrees since 1970. The department has extensive contacts with computer and telecommunications related industrial firms. Dallas is distinguished as one of the top centers for high technology complemented by the Superconducting Super Collider. Applicants should send a complete resume, including the names of three references to: Professor Ian Gladwell, Chair, CSE Search Committee, 208 Clements Hall, Southern Methodist University, Dallas, TX 75275. SMU is an equal opportunity/affirmative action employer. Applications from women and minorities are particularly encouraged. Applications will be accepted until April 1, 1991.

University of California, Irvine. Department of Electrical and Computer Engineering. The Department invites applications from outstanding candidates for several tenure track and tenured faculty positions. The successful candidate must have an exceptional record of research including a significant publication record in archival research journals. In addition, senior candidates must have a record for obtaining substantial extramural funding for supporting research programs, proven ability to teach undergraduate and graduate courses, experience in guiding the research of students, a sense of responsibility for contributing to the welfare of the institution through committee service, and the inclination to assist younger faculty in their professional development. Openings exist in the following areas: 1. Systems and Signal Processing. Positions are available at the assistant, associate, and full professor levels. The department seeks candidates with experience in digital signal processing, adaptive filtering, neural computing, machine vision, spectral analysis, controls, robotics or intelligent systems. It is expected that the candidates will interact with faculty in the areas of integrated electronic circuits, VLSI system design, solid state devices, and parallel processing. 2. Computer Engineering. Positions are available at the assistant, associate and full professor levels. Senior candidates will be given higher priorities. It is expected that the candidates will have experience in the areas of highly parallel computer systems, distributed computer systems, ultra-reliable real-time computer systems and high-level computer design automation. Senior candidates will be expected to take a leadership role in the department of the computer engineering program. 3. Photonic Materials. The candidate for this position is expected to have extensive background and research in (a) materials for high-speed photonics, in particular, III-V and II-VI compound semiconductors; (b) processing, fabrication, and characterization of photonic materials and devices; (c) integrated photonic devices, interconnections, and packaging. The successful candidate is expected to interact closely with other faculty members in Optical and Solid State Devices in order to extend and enhance the research programs aimed at more effective vertical integration of materials, devices, and systems. 4. Electronic Circuits. A position at the assistant or associate professor level will be available commencing in the academic year 1991-92. The person filling the position is expected to have earned the Ph.D. degree in Electrical Engineering or a closely related discipline and to have a thorough knowledge of the principles of operation, analysis, and design of analog and digital electronic circuits. In addition, the applicant should possess a strong background in the theory and practice of semiconductor electronics and be familiar with modern methods for computer-aided design and engineering of integrated electronic systems. The candidate will be expected to take a leading role in the development of departmental research associated with the creation of integrated circuit modules to perform analog and digital functions which will complement existing departmental strength in the design of digital systems. UCI is located in one of the fastest growing areas in the country. Situated in Orange County, in the heart of a national center of high-technology enterprise, both the campus and the surrounding community are experiencing a substantial growth with exciting opportunities. Numerous research and technology organizations in this area provide occasions for collaborative research efforts. Please send your resume and names of four references to: Leonard A. Ferrari, Acting Chair, Department of Electrical and Computer Engineering, University of California, Irvine, CA 92717. Apply before April 15, 1991 to be sure of full consideration. We are

an affirmative action/equal opportunity employer, and women and minorities are strongly urged to apply.

Telecommunications—SMU. The Electrical Engineering Department in the School of Engineering and Applied Science at Southern Methodist University has an opening for a senior level tenure-track position in the area of telecommunications. Rank and salary are commensurate with qualifications. Candidates for this position must be able to provide leadership for the development of a nationally recognized program of research, instruction, and industrial collaboration in modern digital and analog switched telecommunication systems. Of particular but not exclusive interest are the areas of software technology applied to integrated broadband communications and computing environments; network architecture and protocol design for broadband high speed communications; interconnection of local area networks; and performance analysis and modeling of multi-media communications. Candidates must have an outstanding research record, a dedication to teaching, and a commitment to promote cooperation with industry. Dallas' pre-eminent position in the telecommunications field provides many opportunities for collaboration. Interested individuals should send resumes and the names of three references to: Professor Jerome K. Butler, Chair, Electrical Engineering Department, SMU, Dallas, TX 75275-0335. Tel: (214) 692-3113. Applications will be accepted until April 15. Southern Methodist University is an affirmative action/equal opportunity, Title IX employer and specifically invites and encourages applications from women and minorities.

Department of Electrical and Computer Engineering. Northeastern University in Boston seeks tenure track faculty, at all professional levels, in the areas of Computer Engineering (computer architecture, software engineering, VLSI systems design for test and fault tolerance), robotics, digital signal processing (speech processing and image processing), microelectronics (analog and digital systems design and fabrication), control systems, electromagnetics and optics. The ECE Department currently has forty-nine full-time faculty, two nationally and internationally recognized research centers, a large and expanding graduate program, and sponsored research exceeding five million dollars annually. Expansive opportunities for research exist due to one of the highest concentrations of high technology in the nation. Ph.D. in Electrical Engineering, Computer Engineering, Computer Science or related field required with previous academic or industrial experience preferred. Salary and rank are commensurate with experience. Send resumes to: John G. Proakis, Chairman, Electrical and Computer Engineering, 309 Dana Research Building, Northeastern University, 360 Huntington Avenue, Boston, MA 02115.

Head, Penn State Harrisburg invites applications and nominations for position of Head, Division of Science, Engineering and Technology (SET). Starting date: July 1, 1991. Review of applications begins February 15, 1991. Penn State Harrisburg is an upper-division college and graduate center with 3400+ students. The SET Division, with 47 full-time faculty and 710 full/part-time students includes BS programs in Computer and Mathematical Sciences; Electrical, Environmental, Mechanical, and Structural Design and Construction Engineering Technology, and Masters programs in Engineering Science and Environmental Pollution Control. For more information immediately contact: Dr. Charles Cole, Chair, Search Committee, Office of Dean of Faculty, Room 119, Penn State Harrisburg, Middletown, PA 17057. Phone: 717-948-6103, FAX: 717-948-6008. The Pennsylvania State University is an affirmative action/equal opportunity employer. Women and minorities are encouraged to apply.

California State University, Fresno. Electrical and Computer Engineering Department is seeking applicants for two positions beginning in August 1991. An earned Ph.D. and B.S. Degree in Electrical/Computer Engineering are required for appointment to tenure track. Applications will be considered for appointment at all professorial ranks or lecturer, depending on qualifications. The successful candidates may be expected to teach courses, develop curricula, and laboratories in accordance with his/her expertise in the areas of: 1) Electromagnetics, micro-

CLASSIFIED EMPLOYMENT OPPORTUNITIES

wave engineering and/or physical electronics and IC design/fabrication, 2) design of digital systems and computers, computer architecture, robotics and artificial intelligence, and image processing. Candidates with teaching and industrial experience will be given preference. U.S. Citizenship or permanent residence is required. Send applications to: Chairman, Department of Electrical and Computer Engineering, California State University, Fresno, CA 93740-0094, telephone (209) 278-2726. Electrical and Computer Engineering is a strong, high quality program at CSU Fresno with approximately 500 students currently enrolled. The department enjoys an excellent reputation throughout the high-tech industries of California and the West, and with prestigious graduate schools who recruit our graduates. The Fresno metropolitan area of approximately 400,000 residents is nestled among citrus groves and vineyards, and in easy driving distance to the Sierra Mountains and Yosemite National Park. CSU Fresno is an Equal Opportunity/Affirmative Action Employer. The positions are expected to remain open until filled.

Graduate Research Assistantships—The University of Texas at Arlington. GRAs are available at the Automation and Robotics Research Institute (ARRI) of UTA. The positions are for Ph.D. students in the area of robotics and control theory and are available immediately. Send transcript, resume, and references to F.L. Lewis, Moncrief-O'Donnell Professor, ARRI, The University of Texas at Arlington, 7300 Jack Newell Blvd. S, Ft. Worth, TX 76118. UTA is an equal opportunity, affirmative action employer.

The University of Tulsa, Dean, College of Engineering and Applied Sciences. The University of Tulsa is accepting applications and encouraging nominations for the position of Dean of the College of Engineering and Applied Sciences. The University is an independent, comprehensive, doctoral degree-granting research institution with approximately 3,200 undergraduate, and 1,400 graduate and professional students. The College of Engineering and Applied Sciences consists of eight departments: Chemical Engineering, Chemistry, Electrical Engineering, Geosciences, Mathematical and Computer Sciences, Mechanical Engineering, Petroleum Engineering, and Physics. The Dean of the College reports to the Provost, and should be a recognized scholar with a earned doctorate in engineering, the applied sciences, or physical sciences, and should be familiar with current research trends in these areas. The successful candidate must have appropriate credentials to qualify at the rank of full professor with continuing appointment (tenure) in a department of the College. The candidate should possess leadership qualities that will foster constructive relationships with other colleges, the community, and industry. Academic and significant administrative experience is required. Additional information on job responsibilities and qualifications will be sent on request. The position will be available June 1, 1991. The Search Committee will give full consideration to applications received by March 15, 1991; however, applications will be accepted until the position is filled. Applications, nominations, and correspondence should be addressed to: Dale Teeters, Chair, EAS Dean Search Committee, Office of the Provost, The University of Tulsa, 600 South College Avenue, Tulsa, OK 74104-3189. The University of Tulsa is an Equal Opportunity/Affirmative Action Institution.

Tenure track teaching position in ABET accredited Electronic Engineering Technology program. Teach undergraduate electrical/electronic and upper division courses in one or more of the following areas: digital signal processing, electronic communication, microprocessor/computer systems, instrumentation systems, motors/motor controllers, and/or power systems. Master's degree in electrical engineering preferred. BS in EE and MS in closely related field with current, relevant industrial teaching experience considered. Starting date September, 1991; screening to begin February 15, 1991. Forward letter of application, vita and three current letters of recommendation to: Dr. Robert M. Ennick, Chairman, Industrial and Engineering Technology Department, Central Washington University, Ellensburg, WA 98926. Phone: (509) 963-1756 or (509) 963-3691. EEO/AA

Title IX Employer.

Embry-Riddle Aeronautical University. The Avionics Engineering Technology Department invites applications for tenure track faculty positions. Applicants should show evidence of teaching and research ability. Successful applicants must possess a MS in Avionics/Electronics Engineering with avionics design and/or research experience. A Ph.D. in Avionics/Electronics Engineering or related field preferred. Duties will include undergraduate teaching, research and service. Resume and three references should be sent to: Human Resources Department, Embry-Riddle Aeronautical University, E. Nolan Coleman, Chair, Avionics Engineering Technology, Daytona Beach, FL 32114-3900. Women and minority group members are encouraged to apply. EOE

Chairman, Materials Science and Engineering Program. The University of Texas at Arlington invites applications and nominations from scientists and engineers for the above leadership position for the MS&E program. This multidisciplinary M.S. and Ph.D. program is structured around an expanding core of MS&E faculty complemented by faculty from other departments in both the College of Science and of Engineering. The university is committed to a significant expansion of this program. The curriculum offered and research efforts underway in MS&E provide a broad-based education in all materials areas, including structural materials, polymers, composites, ceramics, and electronic materials. UT-Arlington is the second largest component of the University of Texas System with an enrollment of about 25,000 students. This includes the Colleges of Engineering and Science each with about 100 full-time faculty and a combined student enrollment of about 6,800. The university is located in Arlington, a community of 250,000 people in the center of Dallas/Fort Worth metroplex. Excellent opportunities exist for interaction with numerous local technology-driven industries and the Superconducting Super Collider Laboratory, which is only 30 miles from the campus. The individual appointed to this administrative/faculty position will be expected to teach graduate and undergraduate courses and to conduct an active research program in Materials Science and Engineering. Preference will be given to candidates with a proven record of successful academic leadership, teaching and research. The professorial level of the appointment and salary are open and negotiable. Letters of application with accompanying vita and names and phone numbers of three to five references will be reviewed beginning March 15, 1991. Applications from members of minority groups and women are strongly encouraged. Communications should be addressed to: Dr. C.I. Smith, Chairman, MS&E Search Committee, UT-Arlington, Box 19049, Arlington, TX 76019, Phone No: 817-273-2987; FAX No: 817-794-5653. The University of Texas at Arlington is an Equal Opportunity/Affirmative Action Employer.

Endowed Chair in Electrical Engineering, Department of Electrical Engineering, University of Kentucky, Lexington. Applications and nominations are invited for the Robinson Chair in Electrical Engineering. This position will be available on August 15, 1991, or as soon thereafter as possible. Area of expertise is open although preference will be given to candidates specializing in Computer Engineering. Candidates should have excellent national reputations, be able to provide intellectual leadership, have a terminal degree in Electrical Engineering, Computer Engineering, or a related field, and be qualified for appointment as a full professor with tenure in the Department of Electrical Engineering. They should also have demonstrated excellence in instruction and scholarship characterized by originality, creativity, and productivity. Duties of the appointee will include undergraduate and graduate teaching, supervision of graduate students, development of funded research, interaction with industry, and leadership in the Department of Electrical Engineering. Demonstrated academic excellence, scholarly productivity, and leadership ability will be the primary considerations in the selection process. The University of Kentucky is the primary research university in Kentucky with approximately 22,000 students on the main campus and is located in the beautiful bluegrass region of Central Kentucky. The Department of Electrical Engineering has 20 tenured or tenure track faculty members, 450 undergraduate students, and 75 graduate students. Students may earn the B.S., M.S. or Ph.D. degree in Electrical Engineering. Applications, including complete resumes and names and addresses of three references, should be addressed to Dr. F.C. Trutt, Chair, Robinson Search Committee, Department of Electrical Engineering, University of Kentucky, Lexington, KY 40506-0046. Review of applications will begin April 1, 1991 and continue until the position is filled. Women and minorities are encouraged to apply. The University of Kentucky is an equal opportunity and affirmative action employer.

Computer Engineering Department, San Jose State University, invites applications for tenure track faculty position 91-06. Earned doctorate in Electrical or Computer Engineering is required. Positions are limited to US Citizens or Permanent Residents. Hardware design experience is required for 91-06 areas of interest: (1) hardware and software design of CISC, RISC, and stack machines, (2) memory hardware and software design including cache and EDC, and (3) graphics hardware and software design. Rank and salary consistent with qualifications and experience. Open period is from 9/1/90 until position is filled. Please send a letter of intent, a complete curriculum vitae, and names and telephone numbers of three references to Dr. Nicholas L. Pappas, Chair, Computer Engineering Department, San Jose State University, San Jose, CA 95192-0085. SJSU is an equal opportunity, affirmative action, Title IX employer.

Dean of Engineering, Pratt Institute. An outstanding educator/practitioner with commitment to quality undergraduate education and development of new graduate programs, academic and professional experience, academic leadership ability, and an earned doctorate in engineering is sought to serve as dean of Pratt Institute's ABET-Accredited undergraduate School of Engineering. The School offers curricula leading to the bachelors degree in civil, electrical and mechanical engineering. Applications, accepted until the position is filled, should include a letter of interest, resume and names of three references. Please send applications to: Engineering Dean Search Committee, c/o Human Resources Department IEEE, Pratt Institute, 200 Willoughby Avenue, Brooklyn, NY 11205. EOE/Affirmative Action Employer.

The University of Kentucky Center for Robotics and Manufacturing Systems. Applications and nominations are invited for the position of Director, Center for Robotics and Manufacturing Systems at the University of Kentucky. The Director is responsible for developing and administering the programs of the Center and reports to the Dean of the College of Engineering. The CRMS is an interdisciplinary center created by the Kentucky General Assembly. It has a recurring state budget of \$3.2 million and is housed in a new 68,000 square foot facility containing laboratories, computer facilities, satellite transmission equipment, and offices. The mission of the CRMS is threefold: to conduct scholarly research in the broad area of manufacturing, to facilitate technology transfer and continuing education, and to provide extension service to an expanding industrial base within the Commonwealth of Kentucky. Currently, the CRMS has a staff of 30 and five faculty. Approximately two additional faculty positions will be filled in selected areas of manufacturing. A new Master of Science Degree in Manufacturing Systems Engineering is being implemented to support the research program. An active industrial extension program has contacted over 300 manufacturers in the last three years. The successful candidate should have experience in the organization and direction of major research programs in manufacturing engineering and have academic credentials sufficient to qualify as a tenured full professor in a regular faculty position in the College of Engineering. Applications, nominations, and questions should be directed to A.F. Seybert, Chair CRMS Search Committee, 242 Anderson Hall, University of Kentucky, Lexington, KY 40506-0046. Review of applications will begin on April 1, 1991, and will continue until a suitable candidate is identified. An equal opportunity/affirmative action employer.

Director of the Research School of Physical Sciences and Engineering, The Australian Na-

tional University. The University is seeking to appoint ■ Director for the Research School of Physical Sciences and Engineering to succeed Professor J.H. Carver, AM, FAA, FTS, whose term ends in December 1991. The head of a research school is responsible through the Vice-Chancellor to the Council of the University for the operation and development of the School, for its leadership as an academic enterprise and for its administration and financial management. The Director is expected to be a scholar with an international reputation for excellence in one or more of the physical sciences or engineering disciplines represented in the School. The School is a multidisciplinary body devoted to research and postgraduate training and its activities include both theoretical and experimental research. The School consists of a General Physics Division (applied mathematics, atomic and molecular physics, laser physics, optical sciences, plasma physics), an Engineering Division (computer sciences, energy research, electronic materials engineering, systems engineering) and departments of Nuclear Physics and Theoretical Physics. Recently there has been a major increase in outside funding of the School's research. The new Director will have the responsibility for leading the School in developing and sustaining linkages at the highest level with industry, government and other institutions in Australia and overseas. The successful candidate will be appointed ■ Professor of the University until retiring age 65 years. The term of office as Director will be fixed by the University in consultation with the person recommended. Remuneration will be currently, A\$71,962 per annum as professor, plus a Director's loading of A\$7,080 per annum. Those interested in being considered for this appointment are invited to write to the undersigned from whom further particulars may be obtained. The University reserves the right not to make ■ appointment or to appoint by invitation at any time. Closing date: 15 March 1991. R.V. Dubs, Registrar, GPO Box 4, Canberra ACT 2601, Australia.

Government/Industry Positions Open

Electronics Engineer for NE Ohio computer & software distributor to design software & simulation models for data communication networks; design hardware boards for digital communications; test & analyze performance of data communication protocols; design systems to produce high performance peripheral systems; manage information in main frame computers; design electronic circuits & integrate into systems; assist in development of Local Area Network (LAN) products for PC compatible machines; use of Assembly, C, Pascal, Fortran, Basic & Lotus 1-2-3 in analyzing peripheral systems. ■ mos. exp. in above duties required with an M.S. in Electrical Engineering [must have taken 1 course ea. in Analog/Digital Circuit Design; Microcomputer System Design; Digital Signal Processing, & Local Area Network (LAN)]. M-F 8:00AM-5:00 PM. \$30,905/yr. Must have proof of legal authority to work permanently in U.S. Send resume in duplicate (No Calls) to J. Davies, JO#1255636, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, OH 43216.

Manager, Technical Training in Energy for Developing Country Professionals. Nonprofit educational institution seeks manager for USAID-funded project. Must have technical working knowledge of both management and operations of energy industry, including power plants, power systems, energy planning, etc. Experience in professional-level training, manpower needs assessments, human resource development ■ real plus. Knowledge of developing country needs and experience in LDCs desirable. Candidates should have demonstrated ability to work with ■ highly professional and motivated technical and administrative staff. PhD preferred; MS essential. Substantial foreign and domestic travel expected. Write (no phone calls please), including resume and list of people who may be contacted for recommendations to: Department of Science and Technology, Institute of International Education, 1400 K Street, NW, Suite 650, Washington, DC 20005-2403.

Engineer. Research and development for a real-time, parallel computing system. (1) Conduct performance analysis and lead system level design of ■ general purpose parallel system using an orthogonal access model. (2) Analyze the dataflow in a large jet engine simulation program and map the software to the parallel system. Successful candidate must have ■ B.S., M.S. and Ph.D. in Electrical Engineering with 2 years related experience in a research capacity. The candidate must further be able to demonstrate: (1) Complete understanding of orthogonal memory accessing architectures and knowledge of ■ related parallel system such as EMPRESS or Princeton's OMP. (2) Hands-on experience in designing the orthogonal access memory system with a uniform address mapping scheme. (3) Strong background in dataflow analysis. (4) One year experience in parallel programming on at least 2 different commercial parallel computers. (5) Two years experience in graphics programming, using graphics workstations, and use of UNIX and VMS operating systems. (6) Three years experience in Fortran and C programming. Proof of legal right to work in US is required. Permanent residents and US citizens only need apply. Work hours are 8AM-4:45 PM. Salary range is \$46,500—\$55,000. For consideration, mail your resume and a copy of this ad to: Maryland Department of Economic and Employment Development, 1100 North Eutaw Street, Room 212, Baltimore, MD 21201. Refer to Job Order-9046783. Job Location-Columbia, MD. EOE.

Japanese Translation and Interpreting. Japanese technical documents accurately translated by experienced electronics specialist. Business meetings interpreted with skill and sensitivity. References. Field and Countryman, Washington, D.C. Fax 202-543-4630. Telephone 202-543-2779.

Graphics Software Engineer: Req. MSCS or MSEE, 1 yr. exp. development of 3D interactive graphics and high quality rendering software, including UNIX, C, three-dimensional graphics algorithms, and photorealistic graphics techniques. To design, implement, test, document and maintain 3D interactive graphics and photorealistic rendering software. \$49,760/yr. Job site/interview: Research Triangle Park, N.C. 40 hrs./wk. 8am-5pm. Clip ad and send with resume no later than 3/1/91 to Job order number NC 7202216, DOT Code 020.061-640, Job Service, 700 Wade Ave., Raleigh, N.C. 27611 or your nearest Job Service Office.

Communication Software Engineer for computer system and software development company in Southwest Ohio. Design, develop and maintain emulation packages under Microsoft Windows to emulate Unisys Poll/Select ■ well as UNISCOPE terminals; design and develop graphical user interfaces for all terminal emulation package components like Configuration and Installation; develop and maintain applications to emulate Unisys mainframe printers under Microsoft Windows and under MS-DOS as TSRs, using ISRs, device drivers and Poll/Select communication handlers, in 'C' and ■ assembly language; and provide interface to documentation and quality assurance staff to support above products. Job requires Bachelor's Degree in Computer Science or Electrical Engineering and two years experience as a Software Engineer. Experience must be in software development using C and 8086 assembly languages. At least 1½ years of experience must be in Microsoft Windows and include each of the following: Development of Terminate and Stay Resident (TSR) programs, Interrupt Service Routines (ISR) and device drivers; and development of Unisys Poll/Select or UNISCOPE terminal emulation packages under Microsoft Windows. 40 hr/wk; overtime as needed; 8:30 am—5:00 pm. Salary—\$34,000/yr. Must have proof of legal authority to work permanently in United States. Send resume in duplicate (NO CALLS) to C. Bussard, JO#1099749, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, OH 43216. An Equal Opportunity, Affirmative Action Employer.

Communication Software Engineer for computer system and software development company in Southwest Ohio. Design, develop and maintain emulation packages under Microsoft Windows to emulate Unisys T27 (Poll/Select protocol) as well as Unisys UTS 20/40/60 (UNISCOPE protocol) terminals; design, develop, and maintain Configuration DLLs, IBM EEH-

LLAPI support DLL and DDE interface for Unisys terminal emulation packages; design techniques for developing virtual terminal emulation systems which ■ portable across MS DOS and Microsoft Windows; and develop productivity enhancement tools for terminal emulation packages such as Macro recorder and Macro editor. Job requires Bachelor's Degree in Computer Science or Engineering and three years experience as a Software Engineer. Experience must be in software development using the 'C' language. At least two years of experience must be in Microsoft Windows and include each of the following: Development of Dynamic Link Libraries (DLLs) and high level interfaces using the Dynamic Data Exchange (DDE) protocol as well as the IBM EEHLLAPI standard; development of Unisys terminal emulation packages for Poll/Select as well as UNISCOPE communications protocols; and porting MS-DOS applications to Microsoft Windows environment. 40 hr/wk; overtime as needed; 8:30 am—5:00 pm. Salary—\$39,600/yr. Must have proof of legal authority to work permanently in United States. Send resume in duplicate (No Calls) to C. Bussard, JO#1099750, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, OH 43216. An Equal Opportunity/Affirmative Action Employer.

Design Engineer. Will analyze the electronic components of the personal computers. Will determine the appropriate subassemblies and parts which, when put together, will comprise the product to be sold, and the compatibility of disks, hard drives, CPUs, and other essential parts of the computer to assure not only the quality of the product but compatibility of each product with one another. Will test and analyze each product to determine whether they can be properly integrated into finished product. Requires B.S. degree in Electrical Engineering. Education to include completion of one course in each of the following: analog circuit design and analysis, advanced control theory, advanced filter synthesis, digital signal processing and VLSI design. Hours: 9:30 am—5:30 pm. 40 hours per week at \$28,500.00 per year salary. Must have proof of legal authority to work in the U.S. Please send resume to: Illinois Department of Employment Security, 401 South State Street—3 South, Chicago, IL 60605. Attn: Len Boksa, Reference #V-IL 2054-B. No Calls. An Employer Paid Ad.

Senior Process Engineer. Resp. for lithography process engrg. for 6-inch wafer semiconductor fabrication to improve wafer quality & yield. Duties incl. development & improvement of sub-micron lithography process, equipment & procedures. Reqs. a B.S. in E.E., Physics, or Physical Engrg. and 7 yrs. exp. in the job offered or 7 yrs. exp. in semiconductor (photolithography) process engrg. (5 yrs. reqd. with advanced degree). Also reqs. exp. with steppers & projection aligners to achieve submicron processing; exp. overseeing installation & qualification of steppers, coaters, developers, electrical & optical metrology tools; exp. using metrology tools to maintain & improve photolithography process & yield. Salary \$5420/month. Job & interview site: San Antonio, Texas. Apply at the Texas Employment Commission, San Antonio, Texas, or send resume to the Texas Employment Commission, TEC Building, Austin, Texas 78778, J.O. #5424791. Ad Paid by an Equal Employment Opportunity Employer.

Project Engineer. 40 hours/week; 8:00 am—4:30 pm; \$38,000/yr. Job requires: Master of Science in Electrical Engineering degree with major field of study Electromagnetics. Job also requires: 1) 3 grad. courses in electrodynamics covering the following areas: a) transmission lines; b) waveguides; and c) antennae. Job duties: Perform analysis and provide consultation to achieve electromagnetic compatibility (EMC) in vehicles. Use principles of EMC and circuit analysis to perform design reviews on electronic components and systems during their design and development phase to ensure electromagnetic compatibility. Support EMC testing. Oversee technicians and assist customers in defining test procedures and performance objectives. Troubleshoot and prepare test instrumentation. Develop/improve EMC test methods. Specify and evaluate special high and very high frequency instrumentation. Develop/improve software for automated instrument control. Model EMC problems using C programming language in a UNIX environment. Provide technical expertise to technicians, testers, and customers on test methods, in-

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strumentation, and instrument control. Review and interpret test results. Qualified applicants should send resume and verification of requirements to: 7310 Woodward, Room 415, Detroit, MI 48202. Reference #74990. Employer Paid Ad. An Equal Opportunity Employment-Paid Advertisement.

Video Systems Engineer. Design real time operating systems for graphics products for video systems, including development of graphics for Chinese language market. Schedule engineering tasks for design and implementation into overall project. Consult with hardware engineers to provide technical input for hardware design requirements. Coordinate evaluation, testing and production with manufacturing facility based upon product design. 40 hrs/wk, 8-5, \$3,300/mo. Bachelors of Science degree in Electrical Engineering or Electronics and two years related experience in the engineering and developing of real time operating systems for imbedded systems. Proven ability to (1) Read and write Mandarin or Cantonese languages (2) Program using C and Assembly languages. Send resume and proof of legal authority to work in the U.S. to: Colorado Dept. of Labor, 600 Grant Street #900, Denver, CO 80203 and refer to Job Order Number C03195338.

Research Engineer for NE Ohio Nuclear Medical Imaging Co. to conduct research into advanced medical applications for three dimensional nuclear medical imaging equipment. Design and develop customized diagnostic software. Evaluate installation, calibration & test documentation with regard to system installation. Provide installation & maintenance training for physicians & technicians and consult with and advise customers on problems with installed systems. No exp. required in above duties but applicants will qualify with ■ MS in Electrical Engineering and 6 mos. exp. ■ ■ ■ research assistant. MS degree must have included one course each in Computer Visions for Individual Application, Techniques of Pattern Recognition and Digital Signal Processing. Must be able to travel 25% of time nationwide (one wk per mo.). Exp. as research assistant must have included ■ mos. research into laser camera based three dimensional range finders for mobile robot navigation. Exp. must also have included 4 mos. working with UNIX and SUN workstation. Mon-Fri, 9am-5pm, \$37,145/yr. Must have proof of legal authority to work permanently in U.S. Send resume in duplicate (No Calls) to J. Davies, JO#1255640, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, OH 43216.

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Open your eyes and see just how many subjects are covered in the new edition of the Consumer Information Catalog. It's free just for the asking and so are nearly half of the 200 federal publications described inside. Booklets on subjects like financial and career planning; eating right, exercising, and staying healthy; housing and child care; federal benefit programs. Just about everything you would need to know. Write today. We'll send you the latest edition of the Consumer Information Catalog, which is updated and published quarterly. It'll be a great help, you'll see. Just write:

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U.S. General Services Administration

NATIONAL UNIVERSITY OF SINGAPORE



DEPARTMENT OF ELECTRICAL ENGINEERING

The Department of Electrical Engineering invites applications for teaching and research positions from candidates with a PhD degree in one of the following areas:

**Computer Communications
Optical Fibre Communications
Computer Systems
Image Processing/Computer Vision
Microwave Electronics
IC Design/Fabrication
Optoelectronics
Semiconductor Device/Process Modelling
Control Engineering
Magnetics
Biomedical Engineering**

Gross annual emoluments range as follows:

Research Scientist	S\$44,860 - 64,200
Lecturer	S\$53,160 - 64,200
Senior Lecturer	S\$58,680 - 100,310
Associate Professor	S\$88,650 - 122,870

(US\$1.00 = S\$1.70 approximately)

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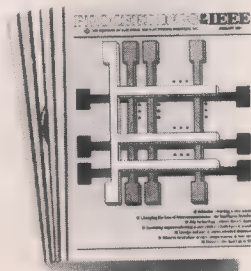
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Electronics for the Autobahn

To stay ahead in the fast-moving electronics field, Germany's automobile makers are working closely with suppliers. Volkswagen, for one, has developed a prototype of a car with an automatic parking system that the company claims will be standard by the turn of the century. By the year 2000, too, Porsche plans to launch a car fully equipped only with optoelectronics systems, and Mercedes-Benz is pushing ahead with state-of-the-art electronic road management technology [THE INSTITUTE, February, p. 1].

All-Japanese launch delayed

Japan's H-II rocket launch vehicle, the first to be built entirely with home-grown technology, is to be launched not in mid-1992 but in the summer of 1993 at the earliest. The postponement is largely due to fuel leaks and fires afflicting the testing schedule of the first-stage rocket engine, the LE-7, which is the National Space Development Agency's first attempt at designing and building a cryogenic engine fueled by liquid oxygen and liquid hydrogen. Problems include cracked fuel-turbopump blades, fuel flow interruptions, and a flawed starting-command sequence [THE INSTITUTE, February, p. 1].

A high-speed train for Korea

Korea is on the verge of issuing a request for proposals for a high-speed rail project aimed at bringing the entire country within two hours of Seoul. It wants joint ventures in which domestic companies acquire relevant technology from foreign partners during the early stages of the project, enabling them to complete the later stages on their own. The three major contenders from abroad are a French consortium utilizing the technology of the Train à Grande Vitesse, a Japanese consortium basing itself on the Shinkansen, and a German consortium employing the newest technology of the trio [THE INSTITUTE, February, p. 1].

Hubble earns NASA poor grades

Deficient quality assurance, the lack of a centralized information system, and a failure to thoroughly test the chief optical instrument used to test the Hubble mirror were responsible for the flawed optics of the Hubble telescope, according to October and November reports issued by the National Aeronautics and Space Administration (NASA) in Washington, D.C.

A December report, issued by a committee appointed by NASA Administrator Admiral Richard Truly and Vice President Dan Quayle and chaired by Martin-Marietta Corp.'s chairman and chief executive officer, Norman Augustine (F), urged the agency to focus on space science; to de-

velop new technology for main rocket engine and space power systems; and to remodel NASA centers along the lines of Federally funded R&D centers administered by universities [THE INSTITUTE, February, p. 1].

Kuwait Section on hold

The Kuwait Section, founded a year ago this month, is in limbo following the country's invasion last August by Iraq. Most of its 273 members are believed to have fled the country, the Kuwaitis to other Arab countries and the rest to Europe, the United States, or their home countries, according to Section chairman Abdul Rahman K. Al-Ghunaim (F), himself now in Jeddah, Saudi Arabia.

In abeyance meanwhile are the 1991 Kuwait Conference on Technology Transfer, the 1992 Kuwait Conference on Communications and Signal Processing, a variety of educational courses, and the computer courses and local plant visits organized by its highly active student members. The IEEE is maintaining the Section and its members in good standing [THE INSTITUTE, February, p. 12].

COMING IN SPECTRUM

Too hot to handle? The U.S. Department of Energy's management of nuclear weaponry and its domestic nuclear energy policy raises questions about its ability to solve the growing problem of nuclear waste disposal and to develop a national energy strategy.

Bandwagon bus. Futurebus gives a system backplane enough bandwidth to cope with highly integrated chips, parallel processing architectures, and data-intensive applications.

X Window flexibility. Based on the X protocol of graphics commands, the X Window System standard improves the ability of a company's computer resources to collaborate over a local-area network.

Vacuum transistors. Combining the virtues of tubes and transistors, these devices are fast, compact, and insensitive to temperature and radiation. Computers, displays, and rooftop dish antennas should benefit.

Destructive testing. Power distribution, telecommunications, and other equipment undergoes destructive testing at AT&T, and elsewhere, the better to armor it against winter's rage and summer's vandals.

Tale of a transform. The Laplace transform, which changes some of physics' most important differential equations into simpler algebraic equations, originated under Napoleon but became accessible to engineers only just before World War II.

Bats and radar. At the University of Illinois's bioacoustics laboratory, *IEEE Spectrum* learned, among other things, how the study of bats might help solve problems of electromagnetic interference with radar.

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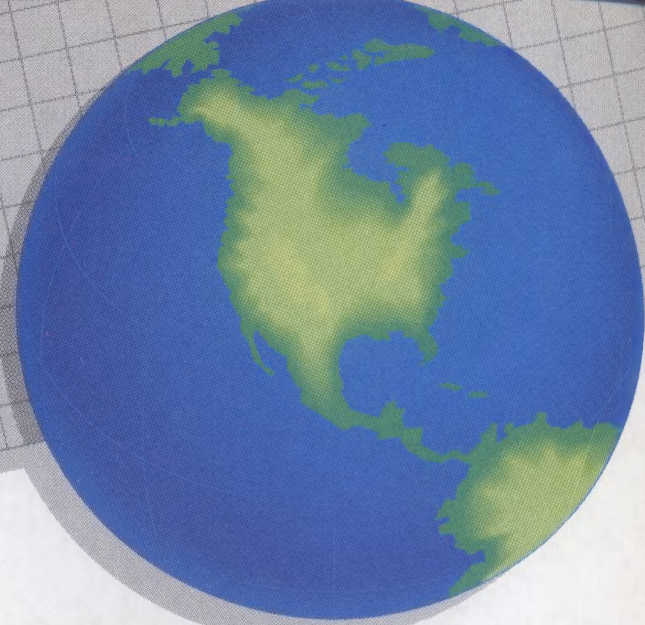
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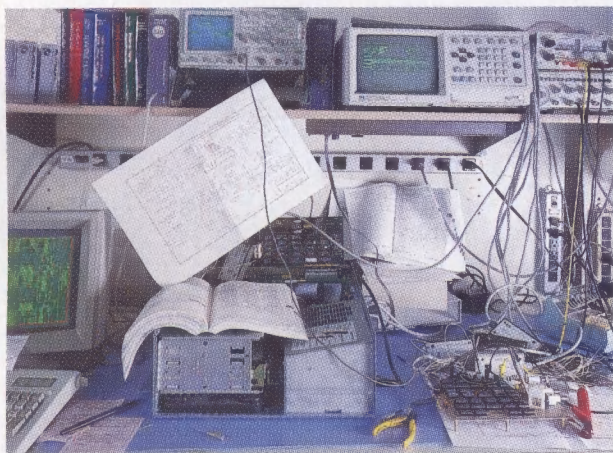
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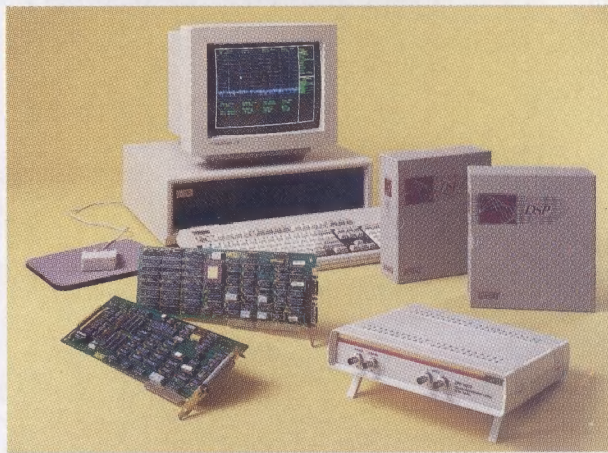


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